MIT'S MAGAZINE OF INNOVATION

# TECHNOLOGY REVIEW

JANUARY 2003

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**Annual R&D Report**
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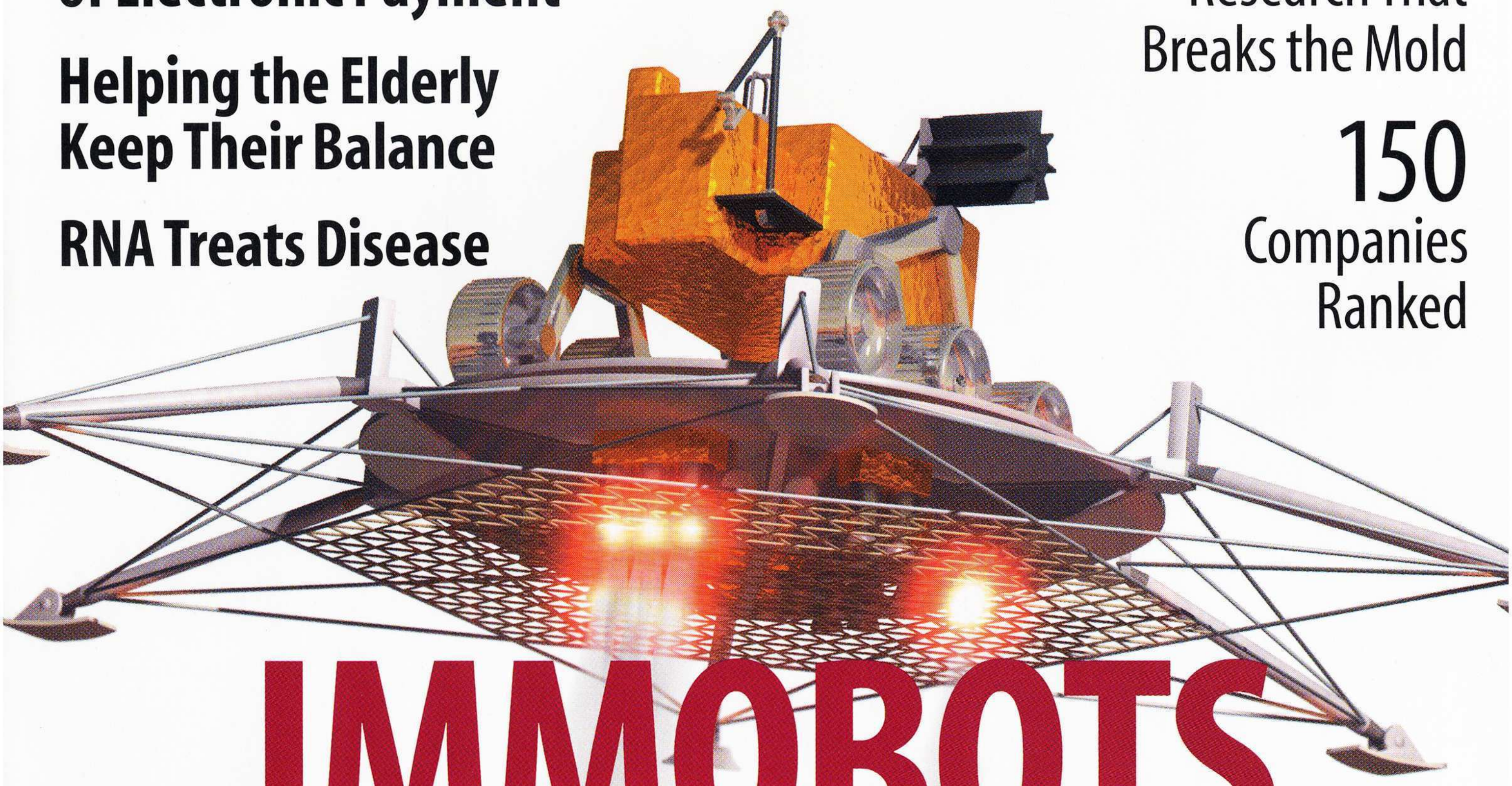

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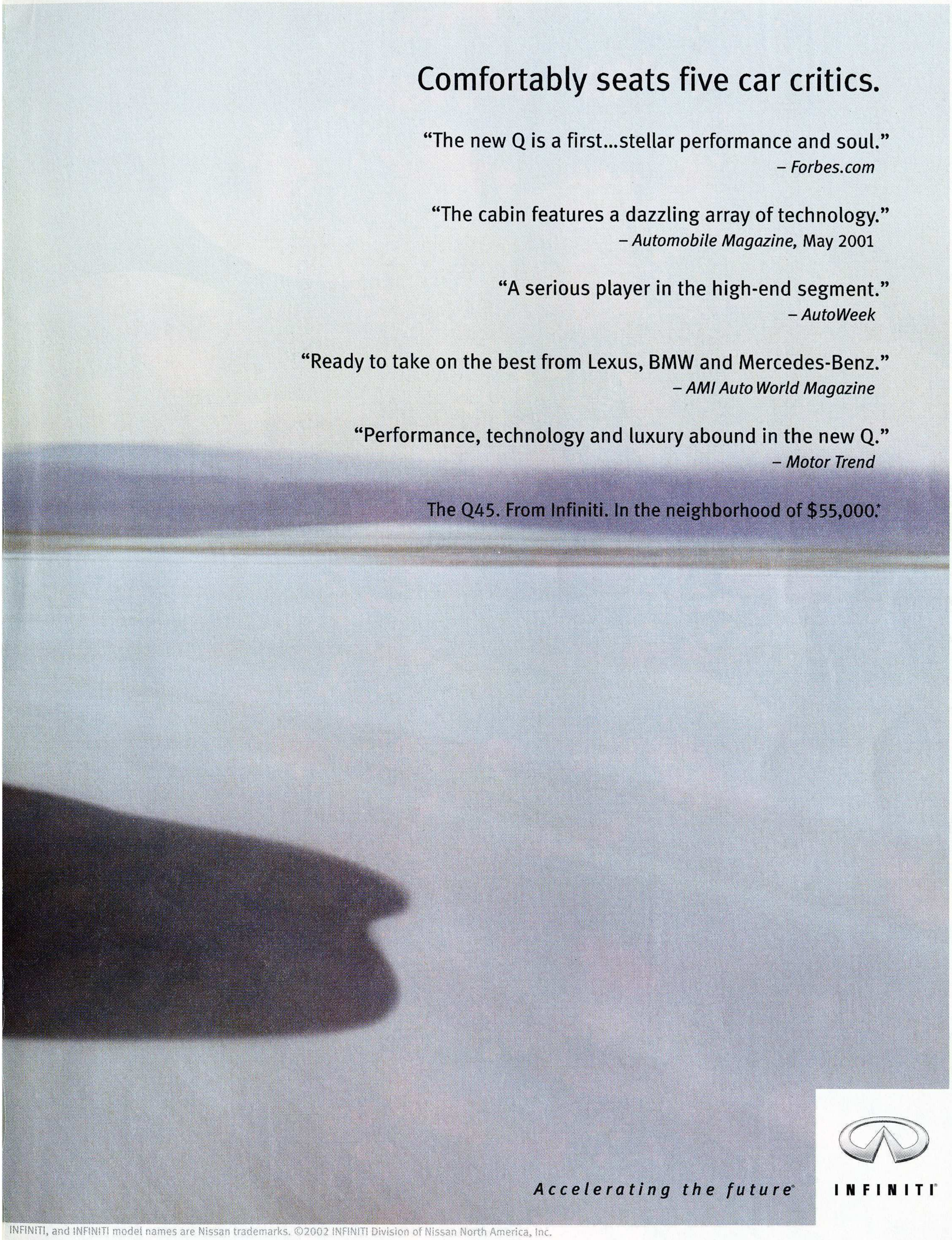
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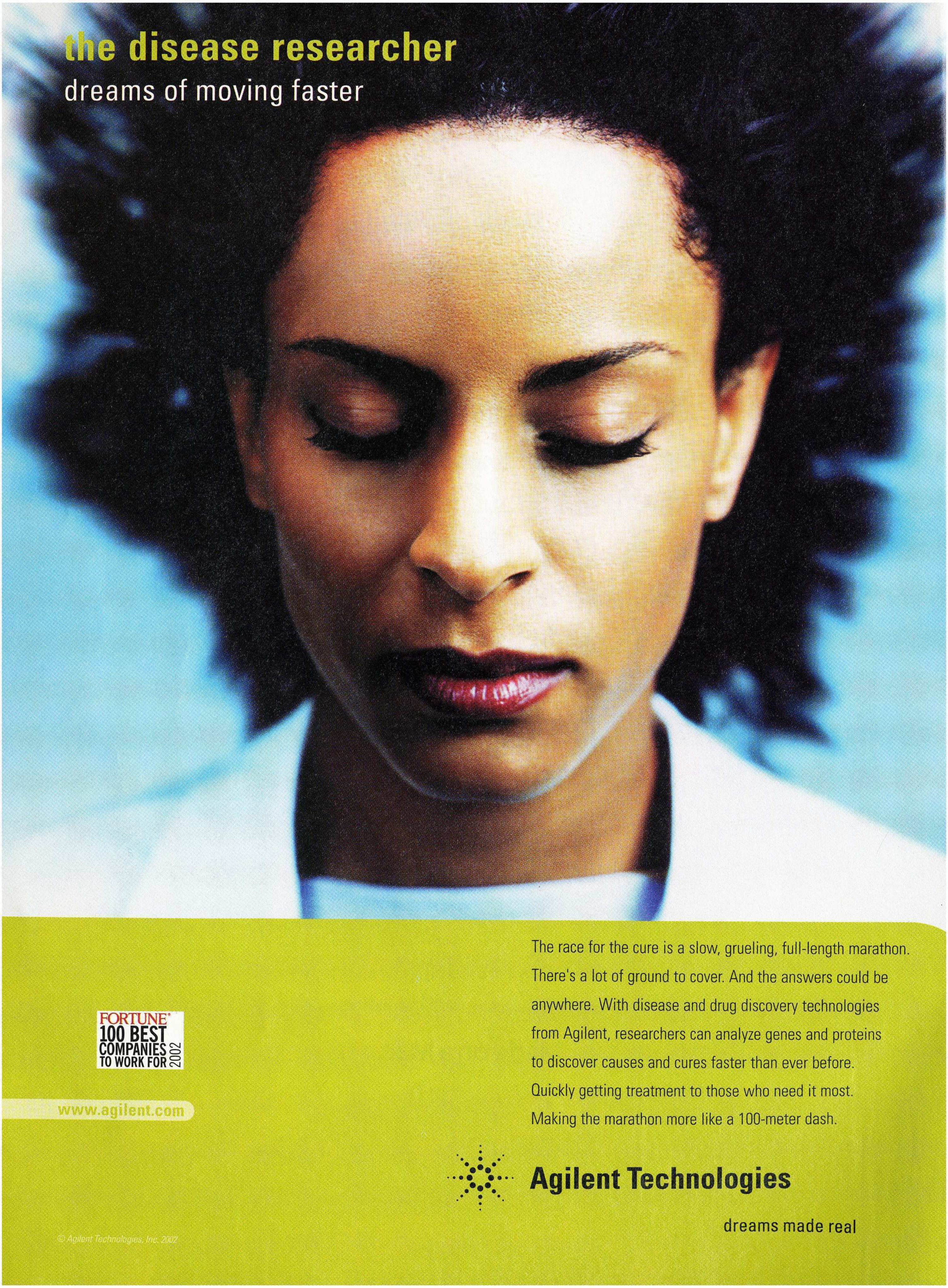
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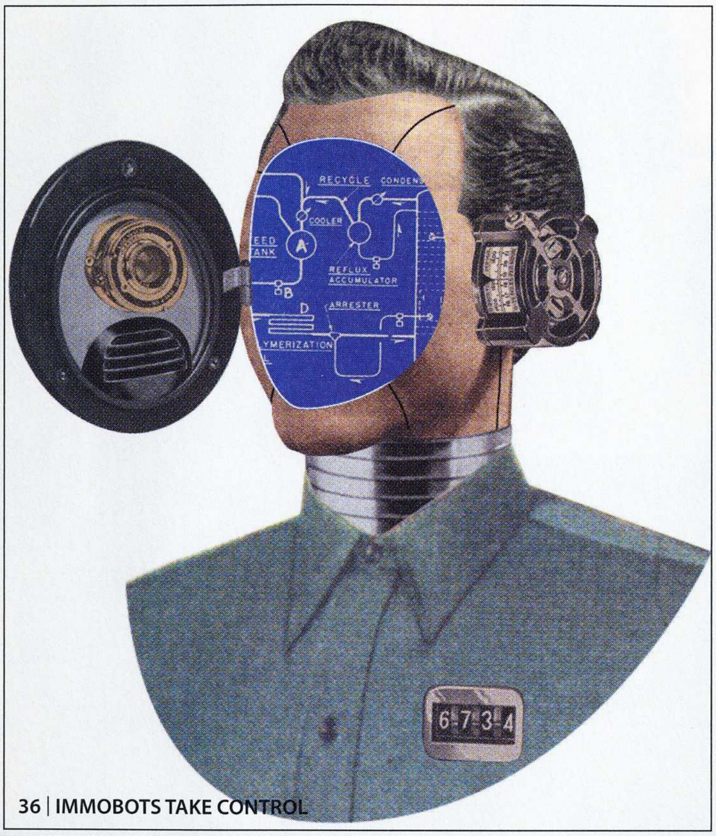

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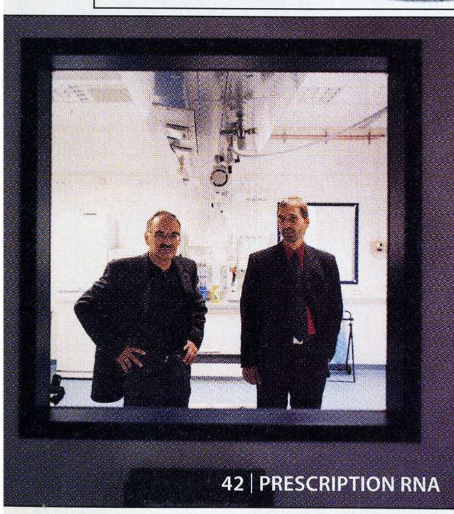

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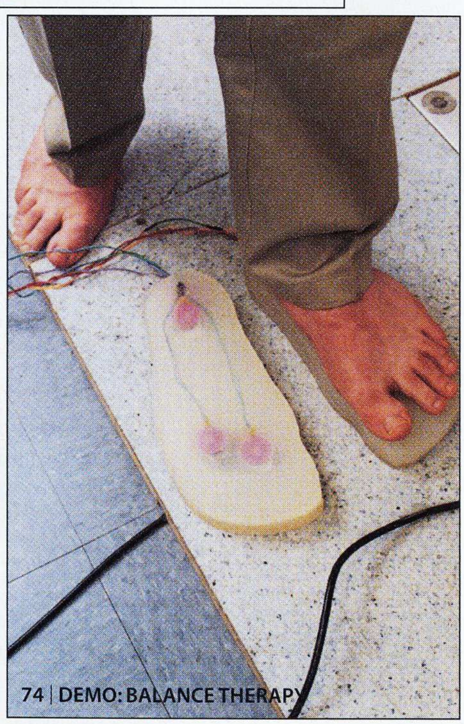

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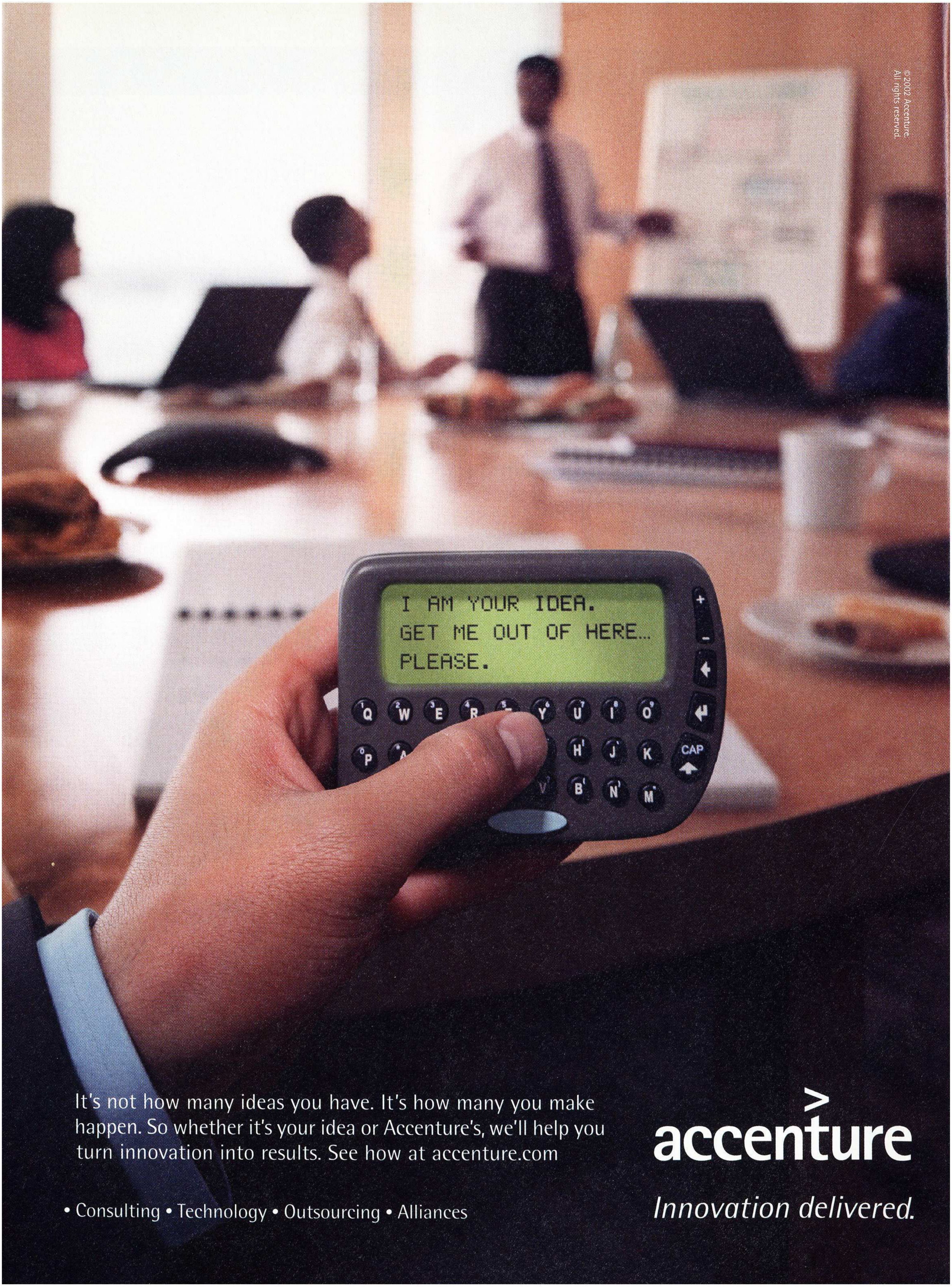
**On the cover: Illustration by John MacNeill.**



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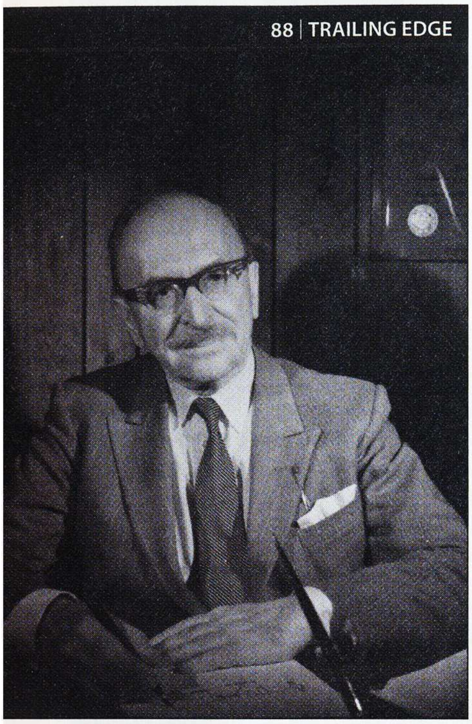



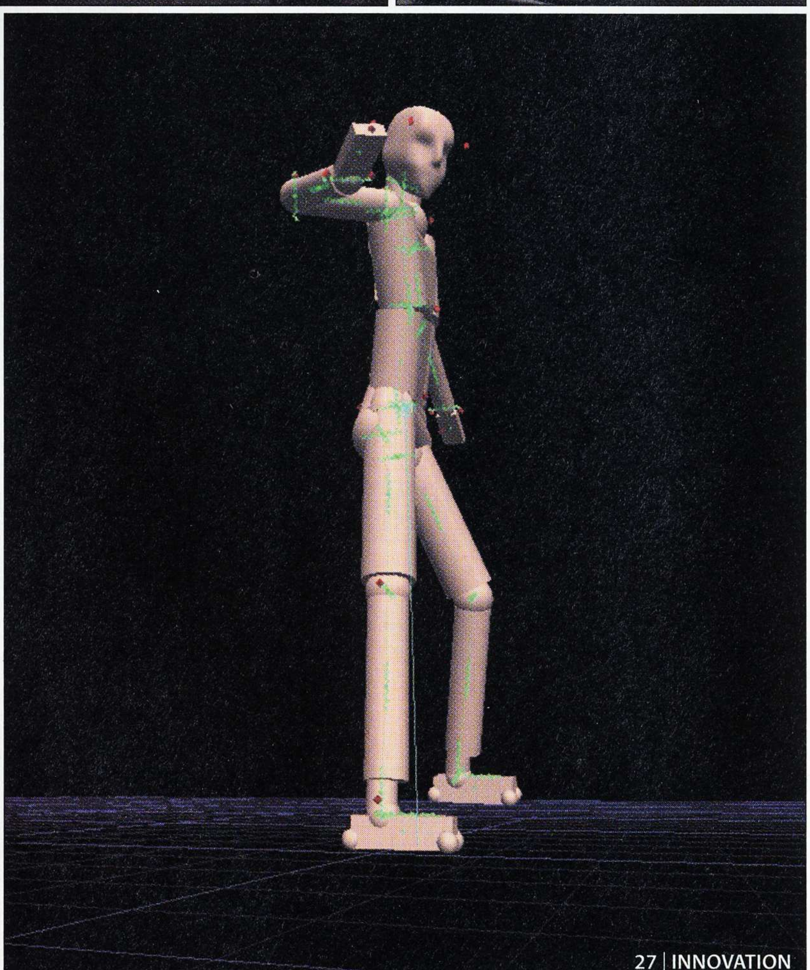


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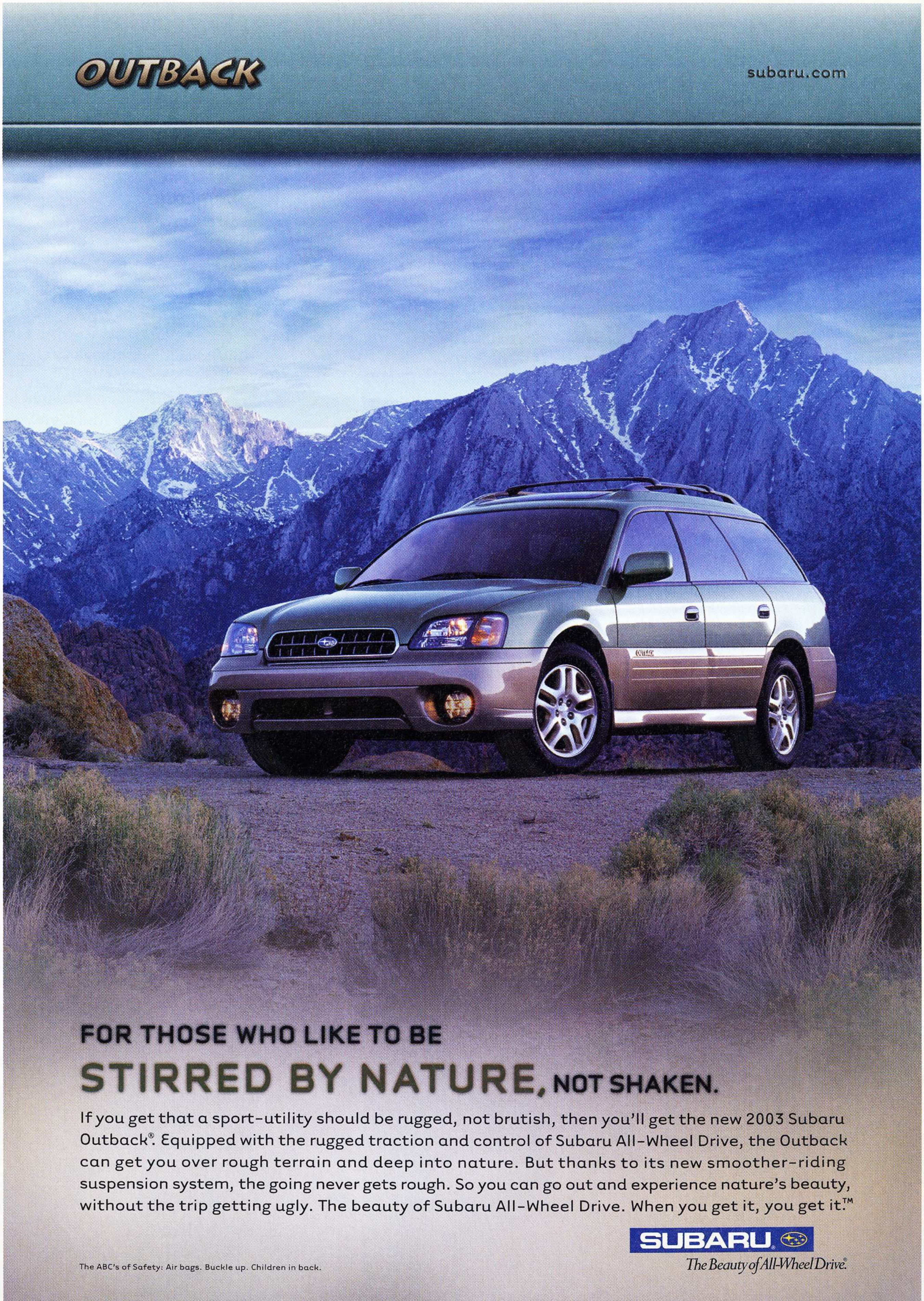
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LEADING EDGE

FROM THE EDITOR

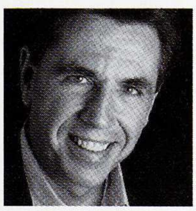
## INNOVATING TO RECOVERY

A flood of innovation will soon hit the United States, Europe, and Asia. This outpouring will be essential to ending the current global recession.

As we all languish under the specter of war, terrorism, layoffs, and accounting scandals, the technology sector is being especially hard hit—so hard hit that many say recovery is at least two years away. However, I believe a turnaround could come in half that time.

I make this assertion partly because my colleagues and I visit regularly with technology leaders. I know the innovation machine—doing real stuff, not fluff—has never let up. And more fundamentally, smart high-tech leaders know they can't simply economize out of recession. Instead, they must innovate to recovery. As Intel CEO Craig Barrett said last spring at a software development forum, "The only way out of a recession is basically to bring out new products, new technology, new capability, and make the end user excited about what you have to offer."

If anything, the commitment to innovation has intensified during these years of slow growth because innovation is what tough conditions demand. Contrary to popular thinking, the Internet boom was not a period of explosive innovation in computers and telecommunications. That recent epoch is better characterized as a time of *imitation*—when almost anyone who parroted the hype about the Web and e-commerce could get funding.



The real technological innovations occurred years earlier—many of them born out of (or made marketable during) the slowdown and recession of the late 1980s and early 1990s, when people got serious about adding value. Few companies responded to that crisis better than IBM. Around 1991, IBM almost saw its research wiped away. But within a few years, it had produced a wave of innovations, especially in semiconductors and storage technology, which quickly exerted their impact on the bottom line. Retired IBM vice president for science and technology John Armstrong once told me, partly in relation to Big Blue's volte-face but also in regard to similar stories at other companies, "People have been so shaken up by the corporate trauma that they realize that they can independently be successful only if they're all successful. Adversity brings people together."

Hard times force companies to shed waste and concentrate on what is truly important. The fresh focus that started a few years ago and continues to guide smart companies today will set the stage for growth in the next few years and beyond—and will give innovative companies the ability to distance themselves from competitors.

For a snapshot of the creative work afoot that will propel the economy in the coming years, take a look at our latest R&D Scorecard *(see p. 67)*, which tracks spending at 150 top companies in 11 technology sectors. Many organizations have reduced their spending, generally reflecting the wise strategy of focusing resources and doing more with less. But let's look at the wingspan of R&D funding in a given industry: which companies are cutting deeply and which are keeping investment high? In telecom, Cisco and Ericsson stayed strong while the other top two spenders—Lucent and Nortel—cut outlays by around 30 percent. By nurturing their technological bases, Cisco and Ericsson ought to be better positioned to innovate out of the recession.

These numbers, of course, are only a guide. And numbers alone do not reveal what, specifically, companies are doing with their technology. In this issue, we've profiled a few cases where corporate labs are pursuing breakthrough projects—long shots that could have enormous impact if they pan out *(see "Research That Breaks the Mold," p. 59)*. Keep reading *Technology Review,* though, and we'll fill in more of the blanks, identifying the best emerging technologies and what they'll mean for your business, your life, and society. We have plenty to write about. —*Robert Buderi*

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# TECHNOLOGY REVIEW

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Dell server consolidation.

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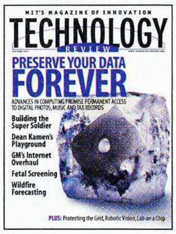
## PRESERVING DATA

Congratulations on one of the best articles I've seen on the digital black hole we're all keyboarding into ("Data Extinction," *TR* October 2002). There are no silver bullets for this problem—not even encapsulation or the universal virtual computer. But there is hope if realization of the seriousness of the issue is matched with a couple decades of bearing down on the problem.

*Stewart Brand*
*San Francisco, CA*

The article on data extinction was an interesting effort to bring the problem to readers who don't think about it on a daily basis. However, there was a bias toward some solutions and a failure to mention others. MIT's massive digital-archiving project, called DSpace, was passed over in silence. The article also didn't mention the thorny problems for digital preservation introduced by the Digital Millennium Copyright Act, which makes it illegal even to research some of the methods mentioned in the article. We can only hope that other, unconstrained countries will save the files we are creating with proprietary software.

*Patricia Galloway*
*Austin, TX*




**Most organizations looking to preserve information have records in document form—not Atari games or Hitchcock movies. One solution: microfilm.**

**Editor's note:** Readers of our MIT alumni edition will find an article on DSpace in the MIT News section of this issue. The article is also available online at www.technologyreview.com. Click on Current Issue.

When comparing paper records with electronic files, you neglect the main reason these paper records are useful today: they are written according to standards. Text is in a widely understood form, such as the English language; drawings are in colors that are visible to the human eye. Likewise, standardization is the key to preserving electronic information. Hypertext markup language (HTML) and its superset, extensible markup language (XML), would be excellent choices for the document format.

*Claudio Oña*
*Cordoba, Argentina*

Your article on data preservation left out one important solution: microfilm. Any records manager or archivist

would be quick to point out the value of microfilm in the preservation of information for the long term. The article states that old word-processing files are "lost forever." This is clearly wrong. In my line of work, I preserve all types of general business documents on microfilm. Most organizations looking to preserve information have records in document form—not Atari games or Hitchcock movies. For these organizations, solutions are present, proved, and being sought after regularly.

*Allen Adjamian*
*Los Angeles, CA*

**SOLDIERS IN THE NANO AGE**

Your article on a nanotechnology-enhanced fighting force ("Super Soldiers," *TR* October 2002) is excellent. At the Army War College, we have been studying the prospects of these developments for some time and have been looking forward to practical applications of nanotechnology; my students and I are largely convinced that the second half of this century will be known as the Nano Age. As your article correctly notes, spinoffs from military investments in this field will pay huge dividends to all mankind. And if it leads to robot soldiers—so long as they are our robots—press on!

*Douglas V. Johnson*
*Carlisle, PA*

**FETAL FORTUNES**

My wife and I recently had a close personal experience with the sort of fetal genetic screening that Jon Cohen discusses in his article ("Fetal Fortunes," *TR* October 2002). About nine months ago, we began to undertake in vitro fertilization. We were lucky: we were able to have 12 good eggs surgically harvested. Nine eggs were fertilized by the injection of sperm. Then we then did something special: we had preimplantation genetic diagnosis. At four or five days of age, one cell was removed from each embryo and screened for Down's syndrome. Due to a genetic error in my DNA, we discovered that we had a one-in-four chance of producing a child with Down's syndrome. Of the nine fertilized eggs, eight grew to maturity, and three were "perfect" genetically. We are now eight-months pregnant with a healthy, non-Down's syndrome baby. Considering my disorder, we would have had repeat miscarriages without this assistance.

*Andrew Davis*
*Sydney, Australia*

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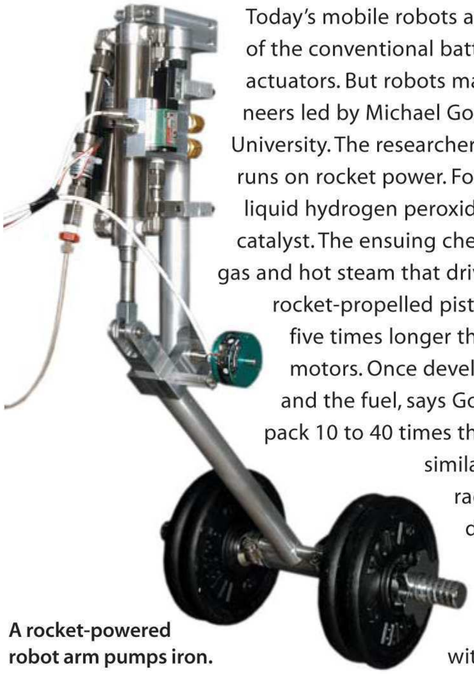
## ROCKET-POWERED ROBOT


A rocket-powered robot arm pumps iron.

Today's mobile robots are severely limited by the energy capacity of the conventional batteries used to power their motors and actuators. But robots may soon take off, thanks to a team of engineers led by Michael Goldfarb and Eric Barth at Vanderbilt University. The researchers have built a novel robot actuator that runs on rocket power. For fuel, the simple, lightweight design uses liquid hydrogen peroxide stored at high pressure and mixed with a catalyst. The ensuing chemical reaction releases a flow of oxygen gas and hot steam that drives a piston. A robot arm hooked up to this rocket-propelled piston can repeatedly lift a 23-kilogram load five times longer than today's best batteries and electric motors. Once developers have optimized both the hardware and the fuel, says Goldfarb, the rocket-powered actuator could pack 10 to 40 times the energy of a conventional actuator of similar size. That's an improvement that would radically change the way robots are designed and used, according to Goldfarb. Vanderbilt has filed an application for a patent on the technology, and the actuator could be commercially available within the next three years.


Colorful robots turn playtime into programming practice.

## COPY BOT

A colorful little robot that resembles an overgrown computer mouse could give kids a chance to explore computer programming even before they know how to read. Users program the Curlybot without writing code. Just turn it on and scoot it across a flat surface. The roly-poly device records every movement exactly, and until it is turned off, it will repeat each movement, allowing children to see the effects of simple programs: how, for instance, a sequence of 90-degree turns can become a square or a short arc can become a circle or spiral. Developed by design firm Ideo's Phil Frei while he was a graduate student at the MIT Media Lab, Curlybot is simple in design. Its brightly colored plastic shell hides two motors, each attached to a separate wheel, and the robot records its position 100 times each second. The frequent sampling allows for movement so precise, says Frei, that it looks eerily organic. Independent of Ideo, Frei is working to bring the newly patented toy to stores in about two years.

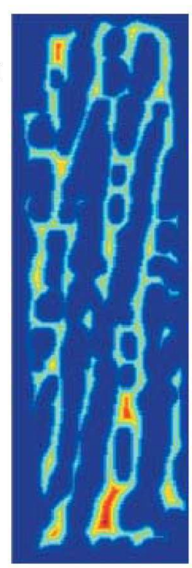
## CONVERSATION SAVER

Talk about rescuing a conversation. Now you can preserve those snippets of cell phone calls you miss when, for example, you pull the phone away from your ear to punch a button. A system developed at Mitsubishi Electric Research Labs in Cambridge, MA, uses a proximity detector to sense when the phone is away from the ear and a memory buffer to record lost chatter. Return the phone to your ear and the playback kicks in, speeding slightly and deleting spaces between words until it catches up with the ongoing conversation. Because the system continuously records and stores the most recent 10 seconds, it can generate an instant replay if, say, a honking horn obliterates part of a discussion. Within the year, the Mitsubishi lab plans to license the technology for use in cell phones and traditional phone handsets, say its inventors, electrical engineers Paul Dietz and William Yerazunis.

## A BONE TO PICK

Technology being developed by Imaging Therapeutics, a medical-imaging company in San Mateo, CA, could enable early, accurate detection of osteoporosis, a disease that afflicts nearly 10 million U.S. residents and leads to 1.5 million fractures each year.

Early diagnosis can make a big difference in preventing fractures, but the best bone-density test now available requires equipment so expensive that few radiologists have it. In Imaging Therapeutics' system, special algorithms reveal microscopic changes in bone architecture as captured in a digital image of a standard jaw x-ray. Such changes can appear in trabecular bone—a type of bone found in the hip and spine, as well as the jaw—even before loss of bone density is detectable. Imaging Therapeutics hopes that within two years it will be able to make its technology broadly available.


Red shows thickest bone microstructure.

COURTESY OF IMAGING THERAPEUTICS (BONE TO PICK); COURTESY OF PHIL FREI (COPY BOT); COURTESY OF DANIEL DUBOIS, VANDERBILT UNIVERSITY (ROCKET-POWERED ROBOT)

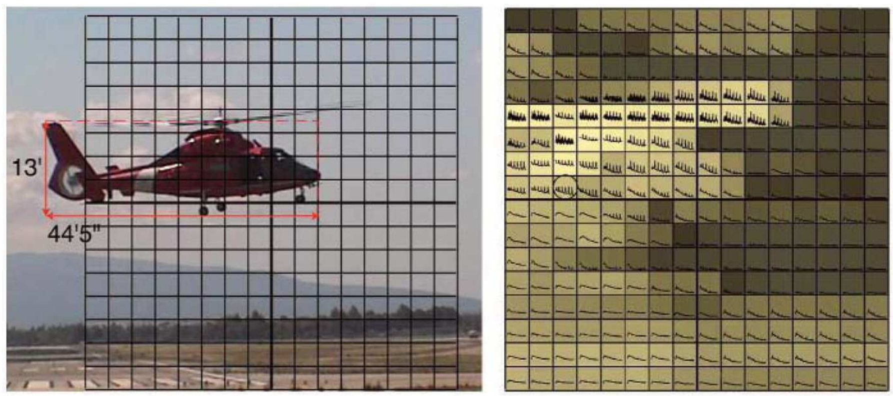
Fuel is vaporized in the pores of this solid-state ceramic "pump."

## SOLID-STATE PUMP

Making a hot blue flame from a liquid fuel (think camp stove or kerosene heater) requires bulky pressurized tanks or failure-prone pumps. But Richmond, CA-based Vapore has built a ceramic, solid-state "capillary pump" that vaporizes liquid fuel and ejects the gas rapidly enough to promote blue-flame combustion—with no accessory equipment. This could give rise to combustion appliances that are smaller, cheaper, safer, and more reliable than those now available. Prototypes of the device—as small as a dried pea and as big as a computer keyboard key—use capillary force to draw liquid fuel into a micrometer-scale, porous structure. Heat applied to the surface of the pump vaporizes the fuel into a gas collection area from which the fuel escapes at high velocity through an orifice. The U.S. Army is considering the technology for lightweight stoves, and Vapore is shopping it around for consumer products; it could also be used for non-combustion applications such as making gas vapor for fuel cells, says Vapore CEO Robert Lerner.

## UNIVERSAL GENE THERAPY

A biotech startup in San Francisco is working on a way to transform gene therapy from a risky experiment into a routine treatment. Instead of inserting genes directly into patients, MandalMed researchers plan to transfer them into cultured cells, ensure the genes are working properly, and then implant the cells into patients. The general idea isn't new, but MandalMed's particular approach is. Rather than harvesting a patient's cells, modifying them, and re-implanting them—a time-consuming process carried out to avoid immune rejection—the company hopes to establish collections of "immune silent" cells that would be accepted by any patient's immune system. MandalMed has begun animal studies with cells that have been modified to treat spinal-cord injury and is testing a number of cell types from a variety of tissues for their ability to evade or suppress the immune system. The researchers' goal is to tailor the cells for such applications as delivering therapeutic proteins to tumors, replacing proteins absent in genetic diseases including hemophilia, and treating multiple sclerosis, stroke, and Alzheimer's disease.




**"Vibration camcorder" detects subtle movements in different regions of an object.**

## SEEING SOUND

That mysterious buzz you hear when you are driving your car can be an annoyance, but unexpected vibrations are often symptoms of deeper technical problems in machines such as aircraft engines or power transformers. That's why physicist Philip Melese of SRI International in Menlo Park, CA, has developed a novel instrument that helps people pinpoint a wayward vibration by allowing them to "see" sound. The device contains optical sensors that detect the minuscule fluctuations in intensity that arise when light reflects off a vibrating surface. The sensors send their readings to a computer, which generates an acoustic map showing the vibration levels in each section of the object.

SRI has packaged these sensors into a "vibration camcorder," which when pointed at a visible object will measure its vibrations. This beats existing measurement methods that require the tester to attach sensors directly onto the test object or to set up intricate laser systems. Several companies have expressed interest in the technology, which SRI hopes to see commercialized within two years.

## PHOTON TRAP

The efficiency of conventional stacked-layer solar cells is compromised because some incoming light is reflected or lost as heat, instead of being absorbed and converted to electricity. Researchers at United Innovations in San Marcos, CA, have developed a new approach that captures incoming photons in a spherical cavity treated with a highly reflective coating and lined with multiple photovoltaic cells. Each cell is covered by a filter that transmits only those photons whose wavelengths match the cell's highest sensitivity range; other photons are reflected within the cavity until they are absorbed by the proper cells. With support from the National Renewable Energy Laboratory of the U.S. Department of Energy, United Innovations has built a prototype and is testing the efficiency of the basketball-size cavity, which generates 1.5 kilowatts, says president Ugur Ortabasi. A computer model predicts that 48 percent of the captured solar energy will be converted into electricity. That would smash the industry record (34 percent), but to achieve it in practice may take several years.

**Spherical solar collector.**

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## EASE OF LEARNING

My cell phone has taught me nothing. On the other hand, my Palm personal digital assistant has been an excellent tutor. Both gadgets are loaded with features I have yet to tap. Both come with instruction manuals thicker than the devices themselves.

But unlike my phone, the Palm helps me learn how to use it better. The cleverly designed Graffiti training function encourages me to practice my digital penmanship so that I can enter data faster. My cell phone gives me virtually no cues or clues for using it. I have to read the poorly written manual or badger friends. I am sure that I use less than 20 percent of the phone's capabilities. For example, I have yet to figure out how to accomplish a three-way call that doesn't simultaneously disconnect everyone. I'm not *that* stupid.

Not to worry: this is not yet another column preaching the virtues of human interface design, convenience, and ease of use. Who would argue against good design? The issue here is subtler and, frankly, more important. Innovators usually focus their resources on getting people and organizations to use their innovations. They typically invest far less capital and ingenuity in improving the ways individuals and institutions *learn* to use those innovations. That distinction is enormous.

All innovators aren't teachers or trainers; however, anyone who adopts an innovation surely has to be a learner. Even the most transparent and intuitive designs present profound learning challenges. A bicycle practically begs to be ridden. But for most people, learning to ride a bicycle is (literally) a pain in the butt.

As instructors and trainers are painfully aware, the quality of teaching often has nothing to do with the quality of learning. There is a difference between teaching people and *helping them learn.* Riding a bike may look easy, but you have to fall down before you get it. Helping a child learn to ride a bike can be a charmingly exhilarating experience. Teaching an adolescent or adult to bicycle is more often an exercise in mutual frustration. Skiing and windsurfing pose comparable difficulties.

To be sure, surfing the Net is easier than surfing Hawaii. But software developers confront stark choices whenever they use innovation as the lure to change how people use the latest version of a Web browser. Should the developers produce an elaborate video tutorial? Or would they get a better return on their investment of time and resources by designing the browser so that it is faster and its intricacies more intuitive and easily understood? In other words, should end users be seen as students who need to be trained or as autodidacts who are ready, willing, and able to teach themselves? Is it the innovator's fault or the user's fault when a proffered innovation isn't used as well as expected?

Some innovators go to ridiculous lengths to prompt awareness of ways to use their products. Microsoft's Office software suite had its noxious dancing paper clip—since retired, according to the company's Web site—which dispensed minimally useful advice whenever it detected a user having difficulties or presumed to know what the user was trying to do. Then again, the world's most influential software company also created "wizards," software templates that help users comprehend the process of preparing PowerPoint slides and Excel spreadsheets. Using the wizard function, users can learn on their own.

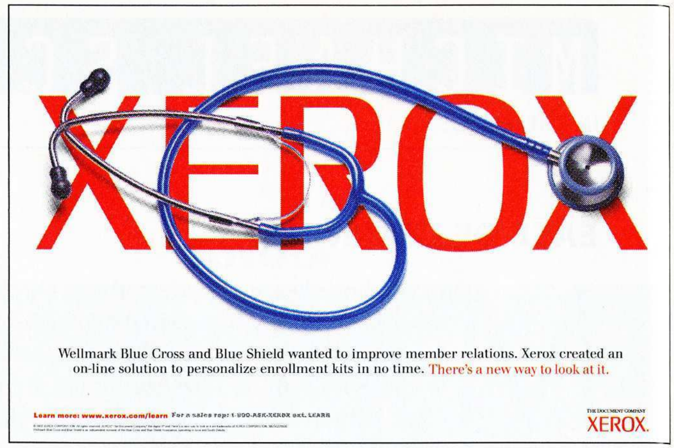
It is surprising that the marketplace provides so few dynamic software-based tutorials that inspire the inner autodidact. And one might think telephone companies would offer toll-free calls to voice-activated help systems that explain how to get more functionality out of their phones. What about automobile makers? Shouldn't their high tech dashboards give some clues about how they can be customized? Nope. Just read the manual.

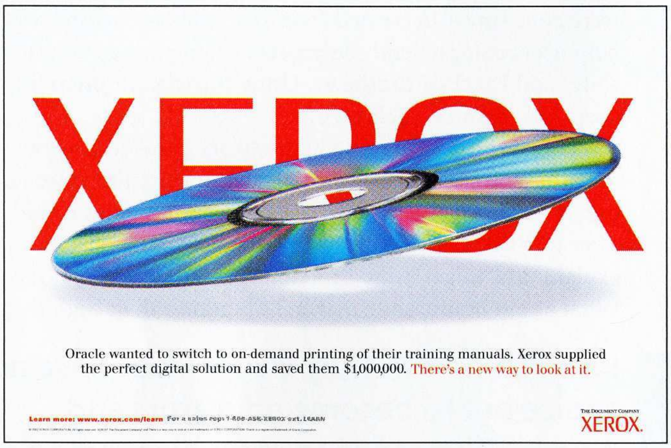
**Innovators with truly clever ideas have no choice but to become educators and trainers. They need to recognize that to overcome customers' resistance, they must marry ease of use with ease of learning.**

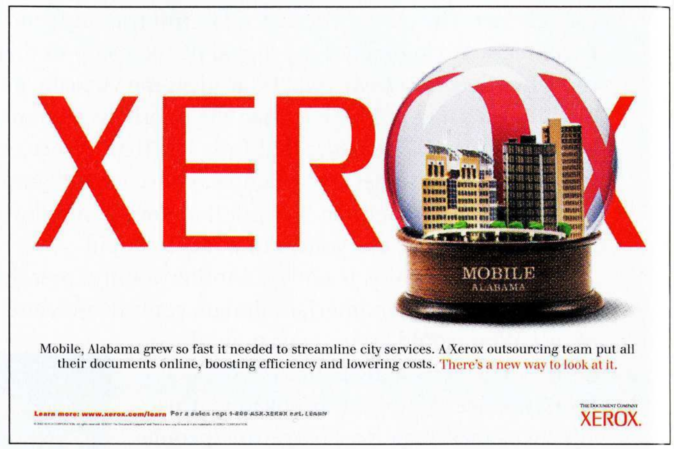
It's shockingly apparent that too many innovators rely not on better training sessions and documentation to support their users' learning curves, but only on Web pages that list frequently asked questions. The rise of third-party training consultancies, outsourced help desks and customer support, and rigorously negotiated service-level agreements is evidence of innovators' intent to dump the costs of teaching and learning on their customers. The economics of innovation adoption are destructively distorted.

This has nothing to do with making innovations easier to use. After all, a bicycle is easy to use; but learning how to ride one isn't so easy—especially if you're an adult. Do you want to be taught how? Or do you want to learn how on your own?

Whether they like it or not, all innovators are service businesses. In fact, innovators with truly clever ideas have no choice but to be educators and trainers, either through the medium of their innovations or through the medium of social interaction. They need to recognize that if they really want to overcome customer resistance, they need to marry ease of use with ease of learning. Encouraging users to read the directions just doesn't cut it. Innovations in learning and teaching will determine which innovations pass the test with customers and which flunk.

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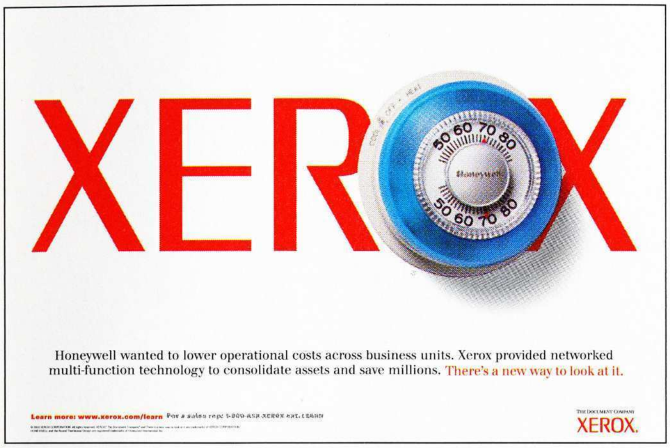


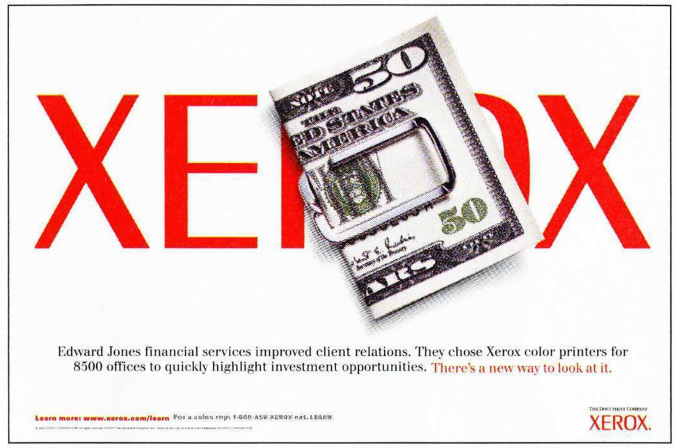


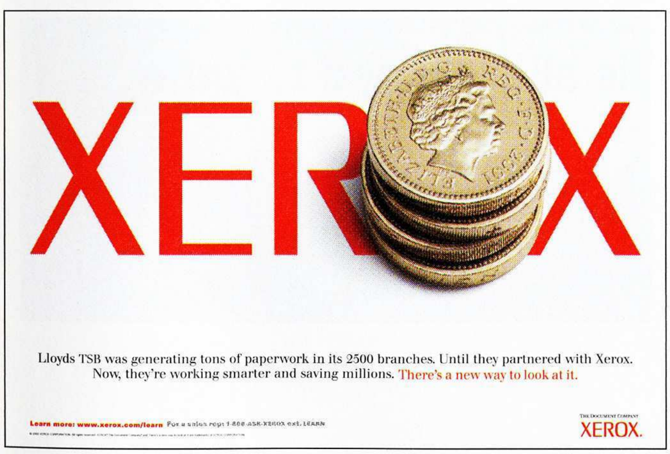


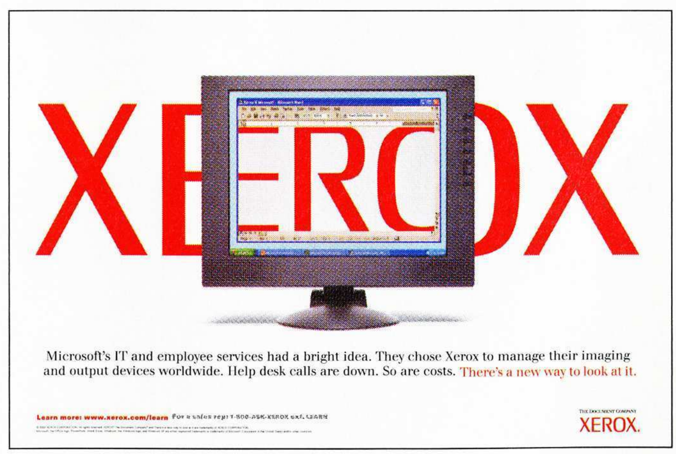


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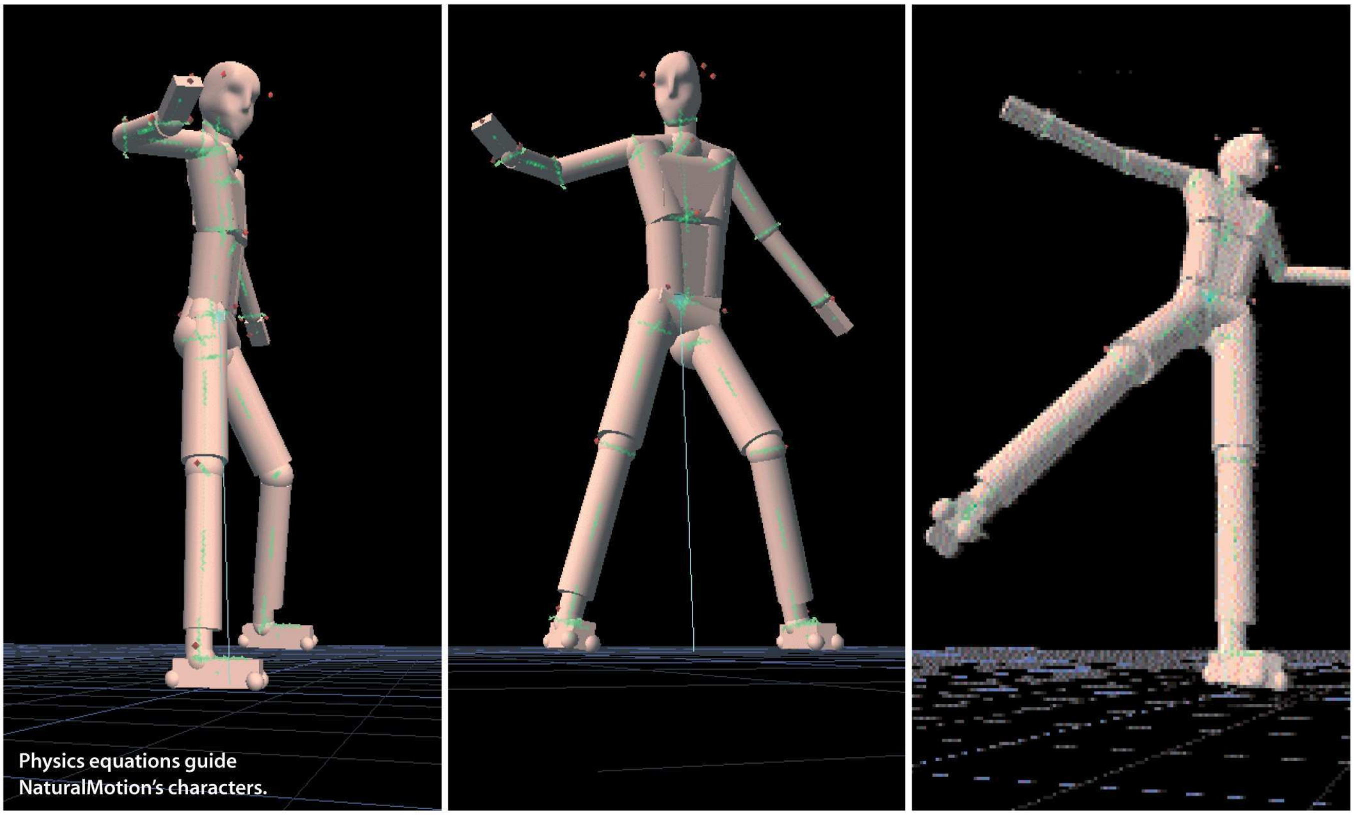


Physics equations guide NaturalMotion's characters.

COURTESY OF NATURALMOTION

## AUTOMATING ANIMATION

### Digital screen stars are becoming more believable—and affordable

Today's digital movie characters are more realistic, interactive, and endearing than ever before. But creating them is still expensive and labor-intensive. Most are either hand-drawn frame by frame with digital pen and ink (and computers that fill in some gaps), or they are based on "motion capture" techniques, which record and digitally mimic the movements of live actors to create on-screen characters. But as movies and video games pack more and more digital creatures onto the screen, animators are turning to physics and new artificial-intelligence methods for faster, more efficient ways to bring their stories to life.

NaturalMotion, a spinoff of the University of Oxford in the United Kingdom, has developed artificial-intelligence software that gives digital characters the power to animate themselves. The approach: a programmer specifies a character's physical shape and properties and adds equations to govern the movement of its body parts. When animators apply a simulated force like gravity or a push from behind, the character responds realistically without further programming. "What you see on the screen is not a computer graphic of the character" dumbly mimicking recorded motions, says NaturalMotion's chief executive, Torsten Reil. "It *is* the actual character." The company's goal is to generate interactive animations in real time, allowing animators to use the technology in video games as well as films, Reil says.

At the Computer Graphics Laboratory of Stanford University, researchers Katherine Pullen and Christoph Bregler have combined automation techniques with the traditional motion-capture approach. Using their system, animators can manually draw the most active parts of a character—its legs, say, during a walking sequence—and use archival motion-capture data to automatically complete the body and give it extra texture. "Within five years, all high-end games will use methods like these," says Casey Muratori, lead developer at RAD Game Tools in Kirkland, WA.

Making characters not only move but also emote convincingly requires a different level of technology—software that generates "believable facial expressions and body language," says Ken Perlin, director of the Media Research Laboratory at New York University. Perlin's group is developing tools that will make it easy for animators to add layers of subtle gestures, for instance, a raised eyebrow or drooping shoulders. Such effects must be drawn by hand today. Though farther from commercialization, Perlin's software is a step closer to animation's larger goal—to dazzle our hearts as well as our eyes. —*Gregory T. Huang*

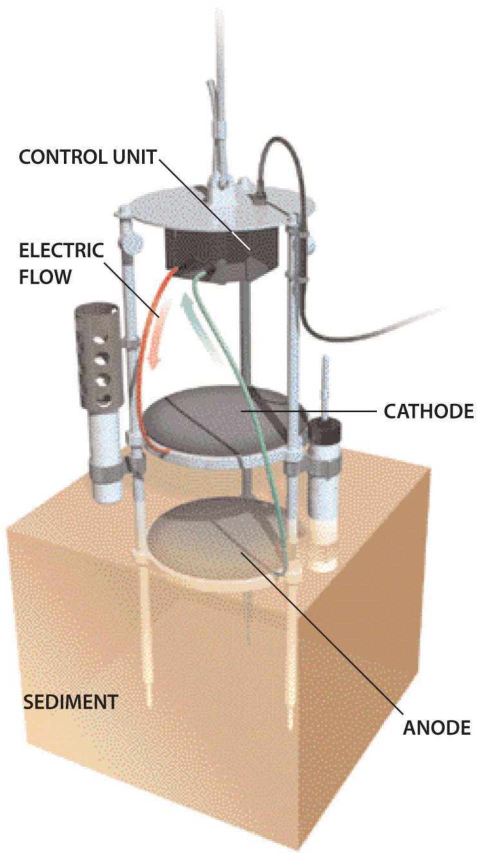
## MICROBE POWER

### A new fuel cell taps the energy of seafloor sediments

**ENERGY** | Leave organic sediments on the seafloor for 80 million years, and they might turn into crude oil. But some microbiologists and geobiologists aren't willing to wait that long to exploit the sediments' latent energy. They're developing a simple, inexpensive fuel cell—just two disk-shaped electrodes and a connecting circuit—that generates electricity when planted in bottom-of-the-ocean muck. "The seafloor constitutes a ready-made battery," says the Naval Research Laboratory's Leonard Tender, who coinvented the device with Clare Reimers of Oregon State University.

The marine sediment along continental coasts is about two percent organic carbon, mostly from dead plankton. Microbes ingest and oxidize the carbon, transferring sheared-off electrons to chemicals in the sediment. The transfer creates a voltage between the ocean bottom and the overlying seawater, a potential difference that generates a current when one electrode placed in the muck is joined together with another above it. Such devices, tested off the New Jersey and Oregon coastlines, have generated steady low-level power for nine months at a stretch. "Every indication is that they would have run forever," says Tender.

An unexpected finding was that much of the power comes from the biological activity of bacteria, called Geobacter, that colonize the electrodes. These bacteria transfer electrons directly to the buried electrode rather than the surrounding sediment, according to recent studies by Derek Lovley, a microbiologist at the University of Massachusetts, Amherst.




**Part of the undersea fuel cell is buried in electron-rich muck. Electricity flows from the anode to the cathode.**

The fuel cells can now generate about one watt of electricity—enough to power oceanographic instruments such as temperature sensors. That power level is "remarkable," says Michigan State University microbiologist Greg Zeikus, who is working on similar microbial fuel cells for generating electricity from municipal wastewater. "That's the target we all want to achieve." Powering military surveillance devices is one possible application. Harbor pollution cleanup is another because, Tender says, the fuel cells accelerate the microbial decomposition of organic toxins.

Tender speculates that seawater fuel cells could even contribute clean, abundant energy to the nation's power grid. Placing hundreds of the devices over deposits of frozen methane found in some coastal seafloor sediments should, in theory, yield large electrical currents. "Right now we're at the one-watt level," says Tender. "But there's no reason why any of this cannot be scaled up to the megawatt region in the right environment." —*Ken Garber*

### Building Better Bacteria

A cheap, renewable, environmentally friendly energy source is the goal not just of many engineers, but also of some biotechnologists. J. Craig Venter, founder of Celera Genomics, which raced against the Human Genome Project to sequence the entire human complement of DNA, has set up the Institute for Biological Energy Alternatives, a nonprofit laboratory that is hunting for ways microbes can provide energy and clean the environment.

Researchers have been experimenting with bacteria that can produce fuels such as hydrogen and methane, as well as those that can remove carbon dioxide, a major greenhouse gas, from the air. But it's difficult or impossible to grow many of the most promising organisms in a lab. So Venter plans to use the latest genetic-engineering tools to amplify these bacteria's gas-producing and air-cleaning traits and transfer them to other microbes that are easier to work with, or eventually to build entirely new organisms.

The institute's first efforts, though, will focus on engineering existing bacteria to produce large amounts of hydrogen for fuel cells or to collect atmospheric carbon dioxide on an industrial scale. Venter says he expects results within one to five years.

Venter's unusual tactics may be just what's needed to coax microbes to work at such a scale, says Gregory Stephanopoulos, an MIT chemical engineer who is an expert on genetically engineered microbes. "They'll be taking an unconventional approach to these problems. I am encouraged by that," he says. For example, Venter says that the method he used to sequence human DNA could uncover useful genes from organisms that can't be grown in the lab. If Venter can extend his record of success, power plants may one day run on vats of microbes instead of fossil-fuel furnaces. —*Erika Jonietz*

SLIMFILMS

## INTERNET INSURANCE

**BUSINESS** | **In April 2002 a German railway sued Google for linking to a Web site that provided instructions for sabotaging rail systems. The case has been bogged down in jurisdictional disputes, but a growing number of similar lawsuits are awakening U.S. businesses to the perils of putting information online.**

**Although there have been no significant monetary awards for damages, the insurance industry has been quick to seize upon the opportunity. Chubb, AIG, and the St. Paul Companies are among the first to introduce special "Internet liability" policies designed to help clients pay settlements or damages if they're sued for posting or linking to material that infringes copyrights, is defamatory, or violates privacy rights. "Companies may not be considering the fact that there is a liability they are carrying just by including links to other people's Web sites," says Bill Rohde, president of global technology underwriting at the St. Paul Companies.**

**So far, most companies aren't buying. For one thing, U.S. courts are still deciding whether standard liability policies implicitly cover Internet risks. At Marsh and McLennan, a New York City–based insurance broker, dozens of clients have some form of Internet insurance, according to Norm Jacobi, managing director and chief technology officer of the firm's technology and telecommunications practice. Still, he says, for most companies "the real interest is in controlling the underlying risks" by safeguarding private data, altering linking policies to avoid legal complications, and educating employees about security threats. And that may be the best way to ensure that liability fears don't slow the Internet economy. —*Wade Roush***

## SENSING SPEED LIMITS

**TRANSPORTATION** | Global Positioning System (GPS) receivers that help drivers navigate unfamiliar roads are already familiar features on high-end cars. And the newest GPS technologies, recently tested in Sweden, tell drivers not just where they are, but even how fast they should be driving.

In tests conducted by the Swedish National Road Administration, researchers added customized receivers and warning systems to almost 1,000 cars. The digital-map databases built into the receivers included speed limit information for roads in several cities. In some of the cars, a black box on the dashboard flashed a light and emitted a warning noise whenever the driver exceeded the local limit. In others, the box displayed the speed limits in addition to the warning signal; and in a third group, the box was linked electronically to the gas pedal and imposed resistance whenever the driver was speeding. Drivers slowed down, and two-thirds of them reported they would like to keep the warning systems in their cars. Some test drivers did complain, however, that the technology led to "less joy in driving" and a "feeling of being controlled."

Despite these discomforts, the Swedish government hopes to make warning systems mandatory for all cars by 2015. Charles Thorpe, director of the Robotics Institute at Carnegie Mellon University in Pittsburgh, calls the Swedish trial "an important step" toward vehicle systems that will use location information to keep passengers and pedestrians safe. Indeed, the Swedish researchers are now busy adding the coordinates of street signs and traffic lights to the national road database. As a result, GPS-based technologies will have the ability within a decade to warn drivers when to stop, says Torbjörn Biding, head of the administration's traffic management division for the administration's western region.

Some major car manufacturers are following Sweden's lead. Christopher Wilson, group manager for telematics and safety research at DaimlerChrysler, expects that by 2012, the company's vehicles will be equipped to deactivate cruise control automatically whenever they enter school zones or turn onto highway exit ramps. By 2022, Wilson adds, cars with GPS receivers and short-range wireless transceivers should be able to tell one another where they are, helping drivers avoid collisions and determine who has the right of way at an intersection. Might robotic cars be the ultimate solution to road rage? —*Julie Claire Diop*

In Sweden's test, a dashboard box displayed local speed limits.

COURTESY OF SWEDISH NATIONAL ROAD ADMINISTRATION (SENSING SPEED LIMITS); JAMES YANG (ILLUSTRATION)

Software from Mahadev Satyanarayanan's Intel lablet will be openly shared.

## CORPORATE R&D SET FREE

### Secrecy is verboten at Intel's network of university "lablets"

**COMPUTING** | At Carnegie Mellon University in Pittsburgh, Mahadev Satyanarayanan is working on a mobile-computing approach he calls "Internet suspend/resume." The idea, says Satyanarayanan, is to be free to stop your work, have your files saved automatically over the Internet, and—when you're ready to resume—find "your world restored" on any computer in any location, as if you were using your personal laptop.

The computer scientist is also experimenting with a new method of transforming his research into real-world technology. Every day, he takes a four-minute walk from his university office to an off-campus research lab funded by Intel. At that lab, the third "lablet" Intel has established adjacent to a leading university, Satyanarayanan has opportunities to translate his vision of Internet suspend/resume into a working prototype—and test Intel's stated commitment to collaborating openly with academic researchers.

"Most companies have real difficulty" reconciling the academic urge for open communication with the corporate imperative to own and profit from ideas, notes Satyanarayanan, who became director of the facility in August 2001. Indeed, many corporations that fund university research force faculty and graduate students to sign nondisclosure and exclusive-licensing agreements. But "Intel has a collaborative model up front," Satyanarayanan says. "The right approach is not to tightly control intellectual property but to treat it the way a university does."

And so far, that's exactly what the lablets are doing. "The vast bulk of the intellectual property produced by this research will be nonexclusive and licensed to all comers," says Intel research director David Tennenhouse, architect of the lablet program *(see "Intel Revamps R&D," TR October 2001)*. At the first Intel lablet, near the University of California, Berkeley, for instance, the operating system behind the lab's self-organizing networks of miniaturized wireless sensors is accessible to anyone who takes out a free license. Indeed, Intel plans to penalize lablet researchers who *don't* share enough. "If a lablet isn't collaborating with its university, then I'll close it," Tennenhouse says.

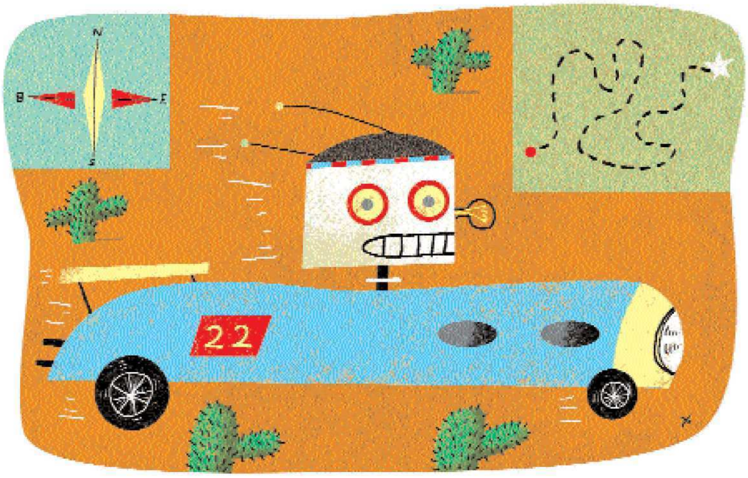
Support for this kind of openness has nothing to do with charity. "Intel stands to benefit in the long run," says Tennenhouse. By accelerating progress on new types of mobile computing and other disruptive technologies, Intel hopes to promote ideas that don't fit within existing business lines but may transform consumers' computing habits and become critical to the microprocessor market within the next few decades.

Gaetano Borriello, the director of Intel's lablet at the University of Washington in Seattle, says the openness guaranteed by Tennenhouse was a big factor in his decision to take a leave of absence from the university to start up the facility. "If it had not been a new model, if Intel had just been doing an established corporate-research lab, I wouldn't have been so interested," says Borriello, whose lablet focuses on "embedded computing," the effort to equip working and living environments with small, out-of-sight computing devices. "Instead of doing this at Microsoft, say, and not being able to talk about my work, I'm at a place where I'm encouraged to talk about it."

For both Intel and the lablets, though, true success might well depend upon accomplishing a different kind of suspend/resume operation—when the time comes to "declare the 'open' phase of a project over and shift the research inside" Intel proper, says David Culler, director of the Berkeley lablet. Culler says such transfers will be critically important, not only because they will help Intel collect on its investment, but also because they will create room at the lablets for entirely new projects. Already, though, Culler believes that Intel has achieved another goal with its lablets: "It has stepped into a position of intellectual leadership."

—*G. Pascal Zachary*

TIM KAULEN/COURTESY OF INTEL




## GENTLEMEN, START YOUR ROBOTS

### Self-reliant roadsters will race for a hefty Pentagon prize

**ROBOTICS** | It may sound like a spectacle worthy of a *Mad Max* sequel, but it will be a real test of real technology. Sometime in 2004, robots will drive the roughly 400 kilometers from Los Angeles to Las Vegas. Competing in a combined on- and off-road race across deserts and mountains, they'll be advancing the technology of autonomous vehicles and vying to clinch a $1 million cash prize.

Robotic-vehicle contests aren't new, but this one, cooked up by the U.S. Defense Advanced Research Projects Agency (DARPA), could be the granddaddy of them all. That's because the route is so long and covers such a variety of terrain, and especially because humans won't be allowed to help via remote control. (They may, however, follow closely behind for safety.) Until now, contests among autonomous vehicles have been confined to small, closed courses.

The race was designed to inspire solutions to vexing problems that face autonomous vehicles, which the armed forces would like to add to their arsenals. For one thing, the robot racers will be challenged to avoid falling into the ruts, holes, and ditches that even today's most sophisticated radar and vision systems have difficulty detecting.

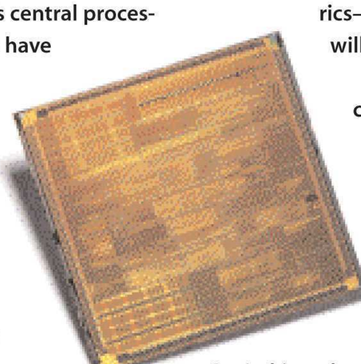
One answer, says Ronald C. Arkin, director of the Mobile Robot Laboratory at the Georgia Institute of Technology, could be advanced sensing technologies that extrapolate hidden depressions from visible terrain or ripples in vegetation. Robot contestants will need vision systems that work in darkness, scorching sunlight, and storms, as well as locomotion systems that can speed through different landscapes. "Think of all the movies about road trips," says Arkin. "All sorts of weird things can happen."

Entrants could include university, corporate, and government lab teams—or even garage tinkerers, says Anthony J. Tether, DARPA's director. Many of the contest's details, such as the exact route and whether repairs will be allowed, have yet to be decided. But it's clear, says Tether, that the race will be "technically rewarding for the future of autonomous military ground vehicles." —*David Talbot*

## WATCHING THE CLOCK

**COMPUTING** | You can't always believe everything you read on a computer box. Even clock speed—that gigahertz-expressed metric most computer buyers associate with a machine's power—may not mean what it used to. A spat between computer titans Sun Microsystems and IBM over just how misleading the measure is has led to a fledgling industry effort to find a more accurate way to gauge a computer's abilities.

The problem is a result of new trends in chip design. Clock speed refers to the frequency with which a chip's central processor does basic operations. Specialized new chips have multiple processors that can end up competing for access to memory, creating bottlenecks that may worsen with future multiprocessor chips, says David Yen, Sun's executive vice president of processor and network products. But while they may perform at a slower clock speed than today's chips, the multiprocessor chips Sun plans to build will run many software programs faster because the additional processors let the chips handle more incoming and outgoing data. Clock speed, Yen asserts, is often "used in a misleading way and overhyped. We're looking for a more appropriate yardstick."

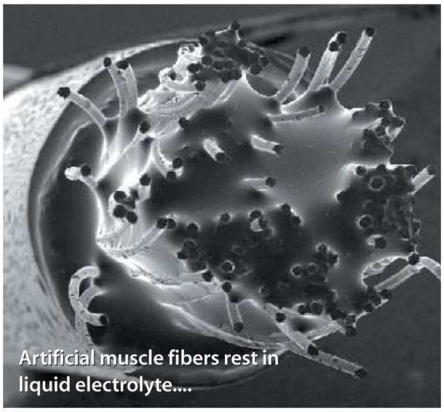


Sun's chips take on IBM multiprocessor chips.

Clock speed, however, is still a legitimate measure of multiprocessor chips that have wide processor-memory connections and therefore don't suffer bottlenecks, says Ravi Arimilli, the chief technology officer behind the development of a new IBM multiprocessor chip. Arimilli dismisses Yen's call for a new benchmark, saying business customers already look at a range of metrics—including how fast their own software applications will run—before they buy a new computer.

But consumers don't necessarily have the same computer savvy. And although today's debate centers on high-end chips used in business servers, it may not be long before PCs have multiple processors. Yen says Sun is talking with chipmaker Advanced Micro Devices about a new way for all users to evaluate multiprocessor chips—a measure "simple enough that people still intuitively get it." That could be a challenge, but it's clear that the gigahertz has had its day in the sun. —*Wade Roush*

COURTESY OF SUN MICROSYSTEMS (WATCHING THE CLOCK); JAMES YANG (ILLUSTRATION)



Artificial muscle fibers rest in liquid electrolyte....

An applied voltage causes them to extend.

## ELECTROACTIVE POLYMERS

### New materials could produce more lifelike devices

In the Artificial Muscle Research Institute at the University of New Mexico, electricity is in the air. When lab director Mohsen Shahinpoor applies a voltage to an artificial "hand" made of a polymer-metal composite, its fingers curl into a fist. Poke around the lab and you'll see robotic fish swimming, wings flapping, and arms lifting—all gaining their muscle from electrically activated polymers. You've seen robots before, but there is something different about these. They look *alive.*

Since the early 1990s, materials scientists and engineers have been developing electroactive polymers for use as sensors, actuators, and artificial muscles. An applied voltage changes the polymer's composition or molecular structure so that it expands, contracts, or bends. The motion is smoother and more lifelike than movement generated by mechanical devices: like muscles, polymers are flexible, unhampered by the clunky rigidity of gears and bearings. Scientists believe that with this similarity to natural motion, electroactive polymers could revolutionize robotics and biomedical devices. Such materials could make it possible to design robots that maneuver with the grace of a human, prosthetic legs that move and feel real, and implantable microdelivery systems that smoothly and quietly pump drugs to where they're needed.

Until recently, however, electroactive polymers have presented practical problems. They consumed too much energy. They couldn't generate enough force. And they didn't last long enough. But researchers in academia and industry have found ways to make the polymers stronger, more robust, and more efficient. These improvements, says Yoseph Bar-Cohen, a senior research scientist at NASA's Jet Propulsion Laboratory and one of the field's pioneers, "will enable faster implementation of science fiction ideas into engineering reality."

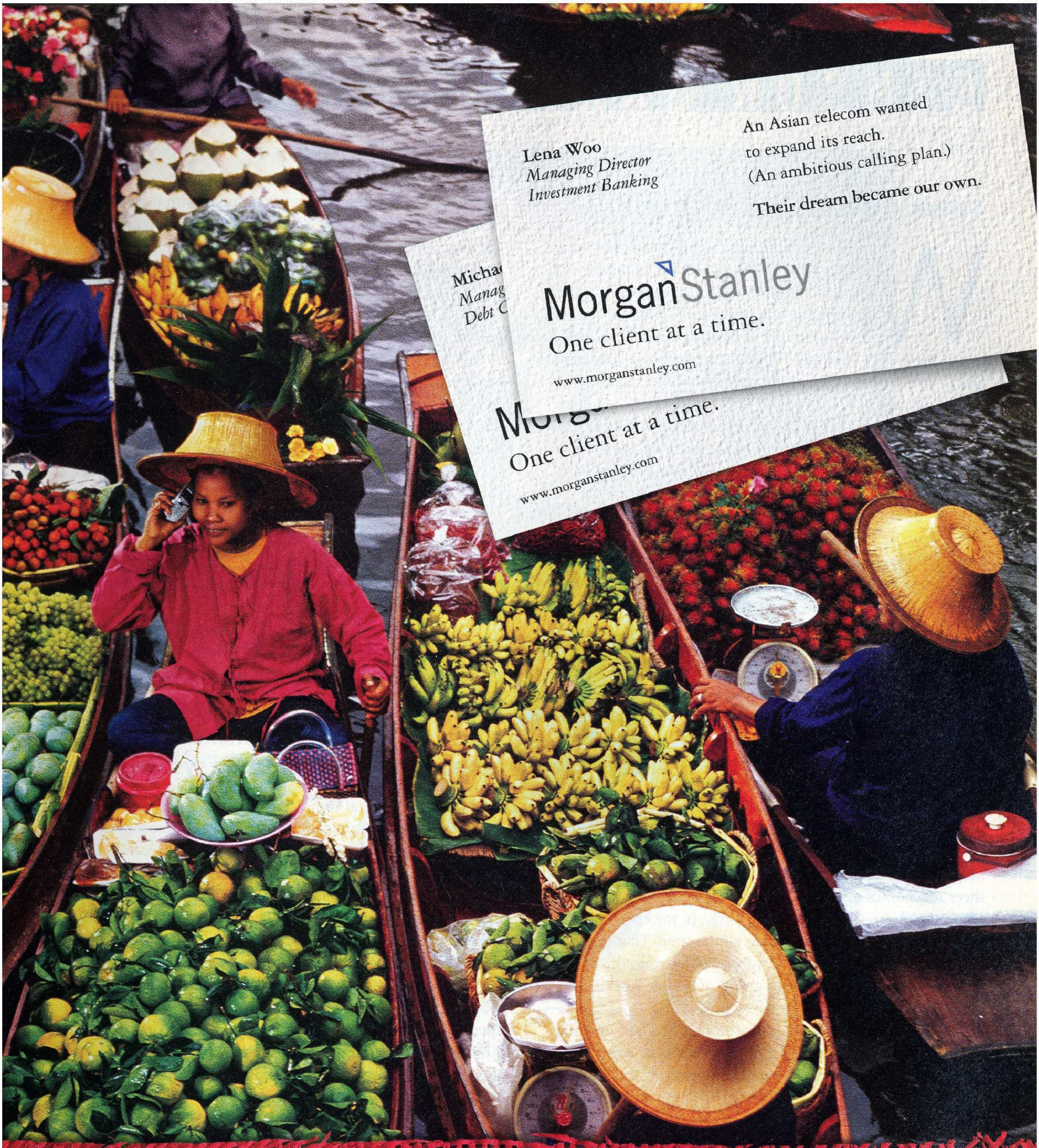
Last September, in a breakthrough that could lead to lower-power medical devices, Qiming Zhang and his colleagues at Pennsylvania State University reported that they had created an electroactive actuator that requires one-tenth the voltage previously needed. Zhang's key advance: a polymer-semiconductor composite that gets more electric bang for the buck and remains very flexible. The advantages of this class of device are its high efficiency and fast response. But "this is just the start," says Zhang. He predicts that pharmaceutical products based on the technology—for example, small wearable insulin pumps powered by low-voltage batteries—could be available within five years.

Benjamin Mattes, CEO of Santa Fe Science and Technology, is building strong, long-lasting artificial muscles out of conducting polymers that expand and contract in response to changes in the flow of ions into the materials. These electroactive polymers generate huge forces at low voltages. Because chemical reactions break down the polymer, earlier versions were slow and able to survive only a few cycles. Mattes's latest device, however, smashes previous records for speed and durability. Its coaxial structure—tiny fibers threaded through a hollow tube and engulfed in liquid electrolyte—allows ions to flow rapidly into the fibers in response to applied voltage. Because he uses a highly stable and conductive ionic liquid as the electrolyte, Mattes says he has achieved "millions of cycles without degradation."

Thanks to such advances in materials science, electroactive polymers are starting to yield useful biomedical devices. At the University of New Mexico, Shahinpoor has demonstrated thin, durable artificial muscles that can lift many times their own weight. Shahinpoor is using the materials to develop implantable aids such as a pump that works like a mechanical pacemaker to compress the heart and a tiny device that corrects vision by gently squeezing the eyeball. His team is commercializing the devices through a spinoff, Environmental Robots in Albuquerque, NM.

There is plenty of work to do before the technology will be ready for market, however. To be successful, Shahinpoor says, the company will need to ensure that the materials are compatible with living tissue and that their functions can be precisely controlled. He will also need to cut manufacturing costs by a factor of 10.

Although the next five years should see electroactive polymers used as components in microsurgical tools, drug delivery systems, and corrective aids, such advances may be only a beginning. To achieve more lifelike robots and prosthetic devices, scientists will need to make materials that are smarter and more interactive. Within 10 years, researchers aim to develop artificial limbs that provide feedback to the user, graceful autonomous robots that are powered by musclelike polymers, and even suits that enhance the strength and endurance of soldiers and rescue personnel. If the research is successful, robotics may truly come to life. —*Gregory T. Huang*




Even for a rapidly growing telecom, the plan was bold: to become Asia Pacific's #1 telecommunications company. Naturally, they came to Morgan Stanley. We set to work to overcome regulatory and regional obstacles, making a once unthinkable acquisition possible. The result? The company grew significantly. And new lines of communication were opened. Such complex challenges are our passion. Such client successes are our mission. What can we do for you?

## THINK OUTSIDE THE MAILBOX

Way back in 1978 I got my first account on an online bulletin-board system. Using my 300-bits-per-second modem, I would log into a computer somewhere in Allentown, PA, and read and reply to messages people had left for me. If there were messages I thought were particularly important, I would save copies on my home computer in a file I called "oldmail."

Nearly 25 years later, the fundamental e-mail paradigm hasn't changed much. Sure, networks and computers are a thousand times faster, and e-mail is now used not just by a few geeks like me but by hundreds of millions of people around the world. But those are only issues of scale. Deep down, e-mail is the same as when I started using it during the Carter administration. A message comes into my mailbox. I read it, and I either file it away or delete it. Although the computer helps, it's my job to be an efficient file clerk.

The problem is that most users don't have the training to be file clerks. Is it better to have one mailbox named "Professional" for all of the professional correspondence, or is it better to maintain a separate mailbox for each correspondent? Is it best to create new mailboxes every year, every decade, or never? I don't know the most efficient way to set up mailboxes so that messages I receive today can be quickly found five years from now. Do you?

None of this matters terribly much if you get five or 10 messages a day. But for those of us who get 100 or more, the sheer mechanics of being a file clerk can consume a significant amount of time—nearly an hour a day, in my case. And we are getting more e-mail messages all the time. That's because e-mail is more than just person-to-person communication: it is the best way to coordinate a group of people working on the same project.

To be fair, the last quarter century has brought one helpful development in e-mail technology: filters, or rules that automatically route messages to the appropriate mailboxes. Filters can be triggered by the From, To, and Cc lines of the e-mail header; a keyword in the Subject line; and even text in the message body itself. Although filters do a good job of splitting one inbox into many, the difficulty of setting up these rules deters most people from using them. Even worse, filters are fundamentally the wrong solution.

The real problem with e-mail today is in the mailbox and folder metaphors. Sure, they feel like apt models. Paper letters are delivered to physical mailboxes. We throw out the ones we don't like, and we file those we want to keep in folders or shoe boxes. But e-mail is different. A physical letter can be in only one place at a time. Why should we enshrine that limitation in our computerized systems?

I'd like to see e-mail systems equipped with just two buttons: Keep and Delete. Pressing either button would move a message out of the inbox. Press Keep and it would be filed in an intelligent database that would automatically characterize all the many different ways you might want to index it. Mailboxes would become keywords. If you wanted to see all the messages sent by coworkers about the Agamemnon project, say, all you'd need to do would be to ask for them—the database would automatically figure out who your coworkers were and which messages related to the project. Software would make such determinations on the basis of mailing patterns, subject lines, and word analysis.

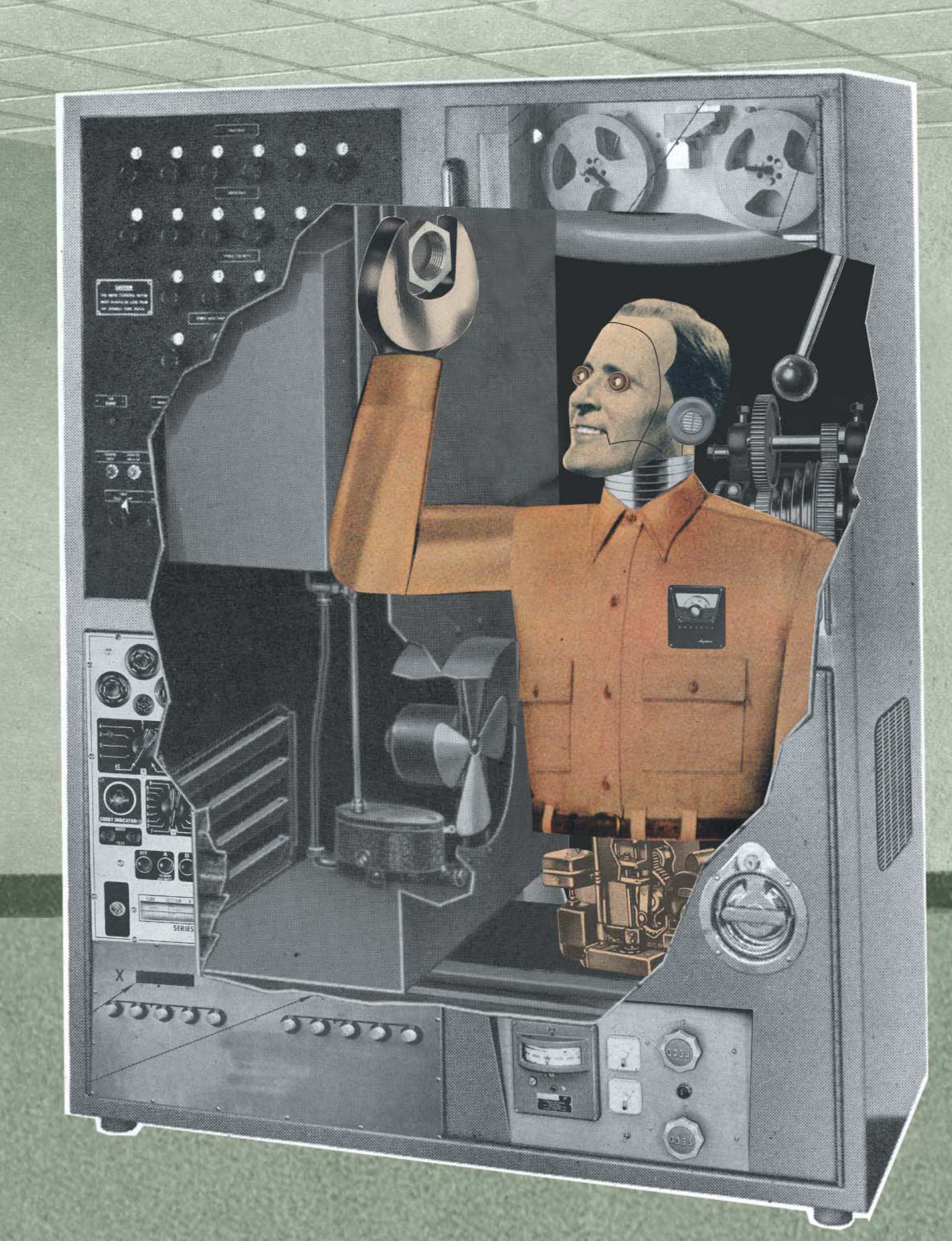
The Delete button would not immediately trash the message. Rather, it would file it away in the same database and schedule the message for erasure after perhaps one week. This would make it possible for you to change your mind and recover a message you had deleted. How many times have you wished you had that power? Researchers are actively exploring some of these ideas.

**The real problem with e-mail today is in the mailbox and folder metaphors. A physical letter can be in only one place at a time. Why should we enshrine that limitation in our computerized systems?**

Earlier this year at the TR100 conference at MIT, Richard F. Rashid, senior vice president for research at Microsoft, demonstrated the Personal Map being developed in Microsoft's labs. Analyzing Rashid's stored e-mail, the Personal Map automatically identified the various projects in which he was involved and grouped his e-mail accordingly. The system even identified the e-mail Rashid had exchanged with his contractor regarding renovations to Rashid's house.

Anyone who wants this sort of technology today, though, would need to turn to the world of open-source software—specifically the Evolution e-mail program being developed by Ximian, a startup in Boston. Evolution automatically indexes all the e-mail it receives, making blindingly fast searches possible. It then lets the user organize messages into virtual folders, or "vFolders," which automatically update themselves every time a new message arrives. For example, you could have one vFolder with all the mail from your mother and another with every message containing the word "aardvark." If your mother sent you a message about her recent trip to southern Africa, that message might show up in both places. It's a good first step, but picking the right searches for these vFolders still needs too much thinking: the computer should do it automatically.

The dramatic success of Google, the popular Web search engine, has demonstrated that the key to solving information overload is a clean interface combined with killer search capabilities. It's time for the world of e-mail to catch up. TR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# immobots take control

IT'S A DANGEROUS WORLD, BUT MACHINES THAT "KNOW THEMSELVES" CAN DEAL WITH CRISES AUTONOMOUSLY—AND OFTEN MORE EFFECTIVELY THAN THEIR HUMAN PROGRAMMERS

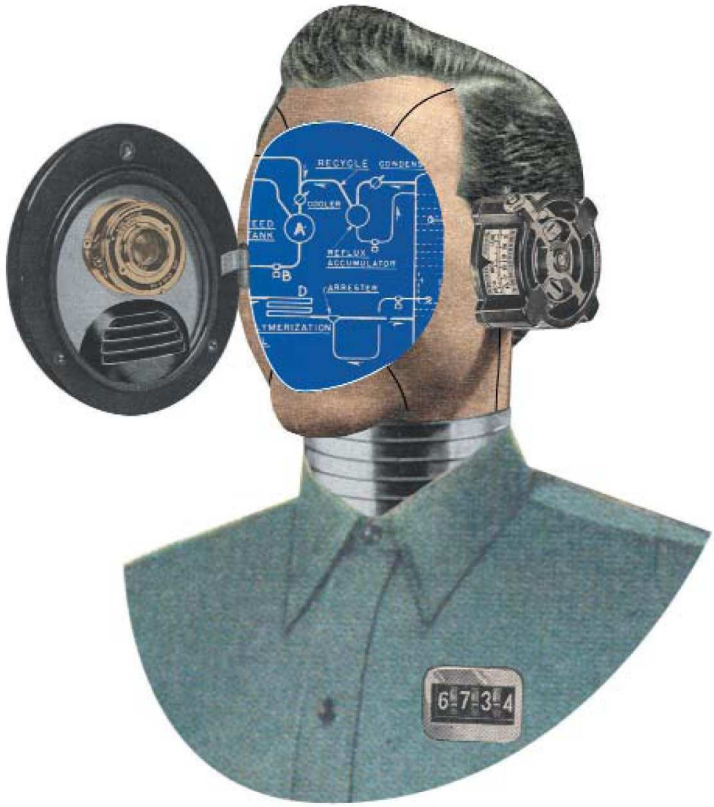
**BY WADE ROUSH**
ILLUSTRATIONS BY DAVID PLUNKERT

The Mars Polar Lander never had a chance.

At 12:02 P.M. California time on December 3, 1999, after an 11-month journey to Mars, the NASA spacecraft slewed its antenna away from Earth in preparation for entry into the Martian atmosphere. That was the last time mission controllers heard from it. According to the scenario a NASA accident-review board deemed most likely, the Lander dropped out of orbit, deployed its parachute, and began firing its descent engines to slow its fall—just as it was programmed to do. But as the craft's three landing legs automatically unfolded, sensors in the legs sent false signals to the Lander's control software, indicating that it had touched down. Not programmed to deal with such a scenario, the software

ignored signs that the craft was still aloft and, at an altitude of 40 meters, shut down the descent engines. Gravity took over, and the delicate craft slammed into the rocky Martian surface with the energy of a high-speed car crash.

That same year, but millions of kilometers away, another NASA craft dealt with crisis more adroitly. Deep Space One had just begun a turn to take optical readings that would guide a planned flyby of a nearby asteroid. As it turned off its camera to conserve energy, the power switch stuck open. This redirected power needed by other essential components, interrupting the maneuver and threatening to put the spacecraft into a semicomatose "fail-safe" mode that could have taken ground controllers weeks to undo. By that time, the asteroid would have been left far behind.




But Deep Space One had something Mars Polar Lander lacked: an onboard robot able to think autonomously and handle the unexpected. Using its engineering knowledge, the robot tried to repair the switch by toggling it on and off. When this failed, it devised a successful plan to complete the navigation maneuver, and the craft proceeded unharmed.

The robot that saved Deep Space One was in the vanguard of a new breed of machines poised to have a big impact in space and here on Earth. Quite unlike the metallic contraptions that march stiffly through sci-fi movies or the mindless, stripped-down devices that heft parts on our assembly lines, the new robots have more brain than brawn. Each possesses a detailed picture of its own inner workings—encoded in software-based models—that gives it the ability to respond in novel ways to events its programmers might not have anticipated. Because many of these inward-focused, self-reconfiguring machines don't move, some computer scientists call them immobile robots, or "immobots."

Immobots are already beginning to crop up in situations where autonomy is important. They are needed either because direct operator control is impossible (for example, in space probes so distant that radio signals take minutes or hours to reach them) or because humans lack the skill or the desire to oversee all the details (in such down-to-earth systems as office machines, water treatment plants, and internal combustion engines). "There are lots of systems in the world that have sensors and actuators, but don't look like traditional mobile robots," says Brian Williams, a former NASA researcher who coinvented Deep Space One's autonomous software and is now a professor at MIT's Space Systems and Artificial Intelligence Laboratories.

Once programmed with immobotic software, Williams explains, these systems "have a commonsense model of the physics of their internal components and can reason from that model to determine what is wrong and to know how to act." Such systems are more self-reliant than typical computers, which are very good at executing mindless, step-by-step instructions laid out for them by software engineers. However, computers are still amateurs when it comes to thinking their way through unforeseen crises such as component failures.

Immobotic reasoning is turning up in everyday systems, including cars, office copiers, and database software. And if advances in the field continue apace, many of the infrastructure technologies we depend on—heating, ventilation, and air conditioning systems; telephone and computer networks; air traffic systems; and electrical grids—might eventually be run by immobile-robot brains. Indeed, entire cities and regions could be transformed into massively distributed immobots. "The problems where you stare at the computer and scratch your head—that's where sophisticated modeling really has a benefit," says Sam Lightstone, a senior technical-development manager at IBM's Toronto Research Lab. "It allows a computer system to make choices and analyses that a human being couldn't."

## model behavior

Deep Space One's grace under pressure marked an early triumph for immobotkind. But in truth, the stuck power switch wasn't an authentic crisis: ground controllers deliberately misled the craft's control software so they could see how Remote Agent, the system developed by Williams and his NASA colleagues, would respond. It was all part of an extensive field test of a programming philosophy known as "model-based reasoning," the core principle of immobot design.

To make machines behave autonomously, most practitioners in robotics and control engineering have long used "heuristic" programs that amount to lists of rules for accomplishing a goal and dealing with contingencies. For example, "If A is true, then do B. If C is true, then do D." The trouble, many artificial-intelligence experts assert, is that traditional, hand-coded software can be either reliable or affordable. Not both.

The Polar Lander mishap and several other software-related failures that marred recent NASA missions demonstrate

that so many of the situations we entrust to software are extraordinarily complex. And human programmers working within tight schedules and limited budgets simply cannot write code that anticipates every contingency. When they try to do so, the software is more often than not so convoluted and slapdash that it contains hidden, potentially fatal bugs *(see "Why Software Is So Bad,"* TR *July/August 2002).*

A model-based program that reasons like Remote Agent isn't built that way at all. It looks like a picture of the machine it was designed to control, painted in the logical language of computers. Both mobile and immobile robots can use this picture to model themselves and choose the fastest, safest, or most cost-effective way to implement an operator's instructions or deal with an emergency. "The idea is very simple," Williams explains. "Provide the program with a physical plan of the system and let the software deduce what to do."

The key to Remote Agent's real-world reliability, says Robert Rasmussen, chief architect of the Mission Data System project at NASA's Jet Propulsion Laboratory, was its collection of very simple models. Each model defined one of Deep Space One's mechanical and electrical components in terms of its possible states. A valve, for example, might be represented by one of two operating modes, "open" or "closed," and one of two failure modes, "stuck open" or "stuck closed." Mathematical rules outlined the possible transitions between modes and the probabilities associated with each one. It's very unlikely that a valve would go from stuck open to stuck closed, for example, so the software knew that it should spend less time investigating such possibilities in the case of a failure.

At the software's higher levels, hundreds of component models were strung together according to the spacecraft's blueprints. In actual operation, the software would begin with no more than a general goal provided by operators, as well as a picture of the spacecraft's current state as indicated by sensors that monitor each valve, relay, gyroscope, fuel tank, and camera. Building from its knowledge of the craft's innards, the software would create a step-by-step plan for reaching the goal or working around problems.

The advantage of this kind of programming is that software developers don't have to lay out every detail of an operation—or imagine and prepare for all possible mishaps. "Engineers thinking about every bad thing they can think of and making sure the spacecraft can respond to those situations is a very time-consuming chess game," says Rasmussen. Model-based programming, by contrast, "provides us with a way to make systems behave the way we want, without spending years and millions of dollars."

## office autonomy

A deep-space probe obviously requires much more autonomy than, say, a photocopier. But heavily used office machines must meet a similar demand for reliability and efficiency—especially when the boss asks for 30 bound copies of the annual report for a board meeting that starts in three minutes. That's why engineers at Xerox and its recently spun-off Palo Alto Research Center (PARC) have begun to build immobot intelligence into high-end copy machines.

Like a big-city airport with flights arriving and departing on shared runways, a copier's biggest challenge is scheduling: it needs to launch the next sheet of blank paper into the printing system as soon as the previous one is out of the way. But as Xerox's previous generation of copiers and printers became increasingly complex, says Daniel Bobrow, an artificial-intelligence researcher in PARC's Systems and Practices Lab, the company noticed that the process was taking more and more time, especially when users selected options such as two-sided copying, sorting, and stapling.

What's more, the machines' heuristic scheduling software lacked full understanding of the interactions among stations, so it treated each of the processes as separate tasks, all of which had to be completed before the next sheet could enter the work path. "The only way to anticipate every possible request was to take any request that was different from the ones [programmers] had thought of and break it down into two or more jobs," Bobrow explains. Even worse, the scheduling software had to be substantially rewritten each time Xerox wanted to add new features to its machines.

THE IDEA BEHIND IMMOBOTIC CONTROL IS VERY SIMPLE: PROVIDE THE PROGRAM WITH A PHYSICAL PLAN OF THE SYSTEM AND LET THE SOFTWARE DEDUCE WHAT TO DO.

But the DocuColor 2045 and the DocuColor 2060, Xerox's flagship printer-copiers, have taken a big step toward sentience. Both truck-size \$90,000-to-\$120,000 machines come with model-based scheduling programs, which PARC researchers designed to optimize moment-to-moment paper flow. "You want to have a number of sheets going through in succession, and when you have two-sided copies coming back around, you want them to be interspersed with things doing the first side," says Bobrow. "So you have to actually look at the timing of these various things and build a model of what's going on."

Say you're making 70 copies of a booklet. Even before you press the Start button, a machine running PARC's model can predict that stapling will be the slowest part of the job and communicate this fact to other components of the machine, allowing them to run concurrently and without creating a big backup. Another advantage, Bobrow says, is that the DocuColor controller models are built from smaller models hard-wired into each component. When a new station such as a scanner or sorter is added, it transmits its internal model to the central controller, providing a painless software upgrade.

"Model-based programming is doing a tremendous job for us in terms of improving [copier] productivity," says Bobrow. Owners of the machines can add and remove components as they like, and they can let the machines toil unattended for hours. What's more, he says, Xerox can use its current models

to simulate new equipment configurations and "evaluate how things would work" before investing a dime in physical prototypes of its next-generation machines.

"This distinction between telling a system how to do its job and telling the system the end result you want is very fundamental," says Robert Morris, director of IBM's Almaden Research Center in San Jose, CA. IBM is working to build what it calls "autonomic" characteristics—model-based features, as well as others that employ classic heuristic programming—into products such as Web servers and storage networks. These features will allow the products to reconfigure themselves for optimal performance, depending on what's being asked of them.

One project, for example, involves building IBM's DB/2 database software with models that allow databases to learn from past queries and suggest ways to rewrite new ones to retrieve data faster and more precisely. Simple efficiency is dictating this move, Morris says. "We spend so much of our time managing these systems and so much of our money paying people to run them. We'd better stop spending so much on the tedium and more on the new technologies."

## hitting the road

If handling unforeseen situations is important for a copy machine, it will be absolutely crucial for machines like the processor-heavy automobiles of the near future *(see "The Networked Car," TR September 2002)*. According to MIT's Williams, officials from Toyota USA recently visited the Artificial Intelligence Laboratory looking for ways to reduce to zero the failure rate of the more than 30 computer processors inside each Toyota vehicle. "At that level," says Williams, "control systems need to have the reasoning and smarts of a robot." And although engineers are still decades away from putting an immobot into the driver's seat—a concept that car buyers may never accept anyway—monitoring a car's internal functions is a very different matter.

Drivers can't spare the attention and don't have the skills to sense problems with fuel pressure, emissions levels, antilock brakes, and any of the other complex systems that influence a car's performance. Modern passenger vehicles contain dozens of processors, so-called electronic control units, that monitor and control these functions with conventional software. But researchers in Europe are already developing onboard diagnostic immobots that run on the same control units and respond to internal automotive failures as soon as (or even before) they occur.

Traditional heuristic programs fall short in such situations because they "fail to capture the first-principles knowledge human experts use" to diagnose problems and plan repairs, says Peter Struss, a computer scientist at the University of Technology at Munich. By "first-principles knowledge," Struss means understanding of the structure, behavior, and interactions of valves, pipes, sensors, and other auto parts. At Occ'm, the Munich software company he cofounded, Struss has spent the last several years building and testing software models of auto parts in collaboration with companies such as BMW, Fiat, DaimlerChrysler, Peugeot, Citroën, and Renault. He's finding that his models identify problems that sometimes elude even expert mechanics.

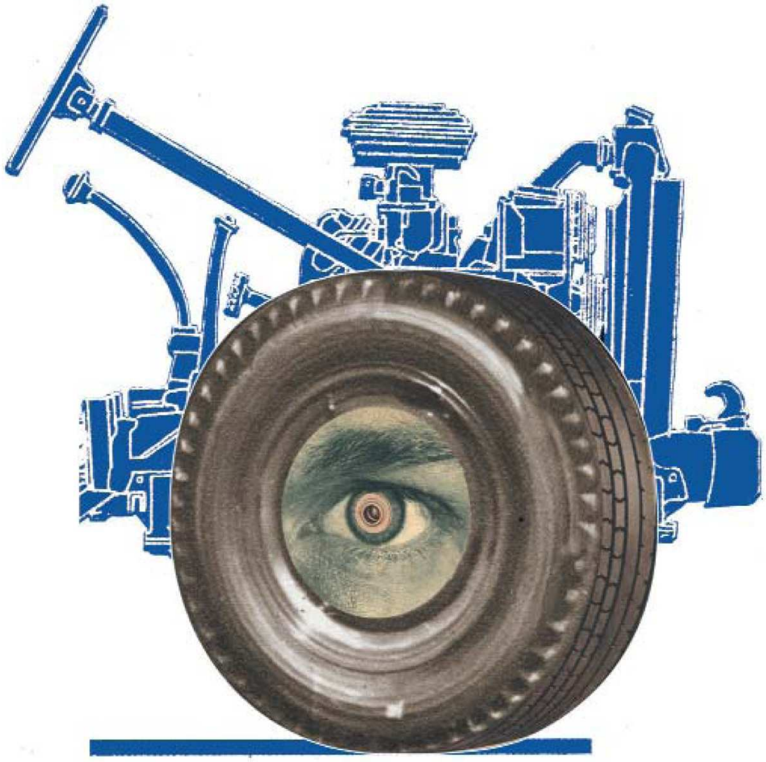
Say the air conditioning in your vehicle won't work. An onboard immobot might quickly deduce that the problem is a malfunctioning fuel-level sensor in the gas tank. "What's the interdependency?" Struss asks. In some cars, he explains, "the AC control system has to ask the engine control unit whether, as a consumer, it's allowed to come on. The engine management system will check whether there's enough fuel. And if not, it will deny the request."

A model-based diagnostic system knows such details in advance. Therefore, if you've got a full tank and the air conditioning still won't work, the model-based diagnostic makes an educated guess at the cause. "Workshop people can read out the diagnostics from control units and see six or seven trouble codes, but it may not be obvious what the ultimate cause is," says Struss. "They cannot see all the interactions." But an immobot can.

In two prototype self-diagnosing vehicles Struss helped build for a project of the European Commission, the immobot software ran on laptops inside the passenger cabins. However, Struss predicts that as early as 2004, similar model-based programs will be built into new cars' onboard diagnostic modules. Meanwhile, he is developing programming tools to help automotive designers build cars with diagnostic systems in mind, rather than (as is the case today) adding them as an afterthought. This means, for example, making sure sensors are always placed where they'll return the data an immobot needs to identify—and someday soon, correct—component failures.

**TO MECHANICS WORKING ON A CAR, IT MIGHT NOT BE OBVIOUS WHAT THE ULTIMATE PROBLEM IS. THEY CAN'T SEE THE INTERACTIONS BETWEEN SYSTEMS, BUT AN IMMOBOT CAN.**

The focus of Struss's work and related studies in Europe—including a project at France's Centre National de la Recherche Scientifique to build a model-based system that will help garage mechanics isolate faults in electronic circuits—indicates that when immobot software finally makes its mass-market debut, it will almost certainly be in the automotive realm, says computer scientist Louise Travé-Massuyès, director of the French project. "The major problem in automobiles," she says, "is the increasing complexity of electrical systems, which means that companies are looking for intelligent tools to help them analyze their products." The key economic and safety advantage of model-based diagnosis, she argues, is that "faults and symptoms do not need to be anticipated." In other words, software designers need only spend their time learning how a car's systems should act, not how they might go wrong.



and long-term responses: treating the water immediately to remove the iron and investigating the most likely cause of the algal bloom, excess nutrients from fertilizer in agricultural runoff.

A prototype advisory system is being tested in Porto Alegre. But building complete and accurate models of processes rather than just parts—and making all those models work together—remains a bit beyond the state of the art, Struss says. It's "difficult because you cannot enumerate all the components. Sometimes you don't know what they are."

While these challenges are being worked out, immobot software is making its way into smaller, self-contained systems such as copiers and cars. Before large-scale infrastructure technologies can be endowed with model-based reasoning abilities, however, researchers must overcome another barrier: the skepticism of old-school engineers who are accustomed to keeping their machines on the short leash provided by heuristic control software.

At NASA, for example, cautious mistrust of truly autonomous software almost killed Remote Agent even before Deep Space One left the ground. "Mission managers are by their nature extremely risk-averse people," says Ken Ford, a computer scientist who directs the Institute for Human and Machine Cognition at the University of West Florida. Ford, who was associate director at NASA Ames Research Center at the time Williams was developing Remote Agent, says, "In fact, it was hard to get them to fly it at all, even as an experiment."

But the success of Remote Agent, along with other demonstrations of model-based reasoning, may be slowly swaying the opinions of even conservative engineers. The Jet Propulsion Laboratory's Rasmussen, for instance, is working with Williams's group to develop a model-based program that has been tentatively designated as the main control software for the Mars Science Laboratory, scheduled for launch in 2009. In Edinburgh, Scotland, a small company called Intelligent Applications is working with General Electric International to sell its model-based software for monitoring and diagnosing the behavior of power-producing gas turbines. And the European Commission has launched a project to develop model-based failure-management software for commercial aircraft.

Eventually, researchers say, immobots could become pervasive, helping to control some of our most important infrastructure technologies. In air traffic management, for example, Williams suggests building immobotic systems that would use sensor data from satellites and ground stations to assess local weather conditions, automatically identify and select the safest, most efficient flight paths, and redirect air traffic.

"At the grand scale," Williams says, "you can address a set of problems people have never tackled before." If he and his colleagues are right, the only way to make infrastructure technologies autonomous without increasing the risk of massive software-related failures may be to program them with distinctly human qualities, such as the ability to plan ahead and solve problems creatively. And in a world that seems increasingly dangerous, knowing that immobots are looking out for themselves—and for us—could be a source of comfort. TR

## colossal control

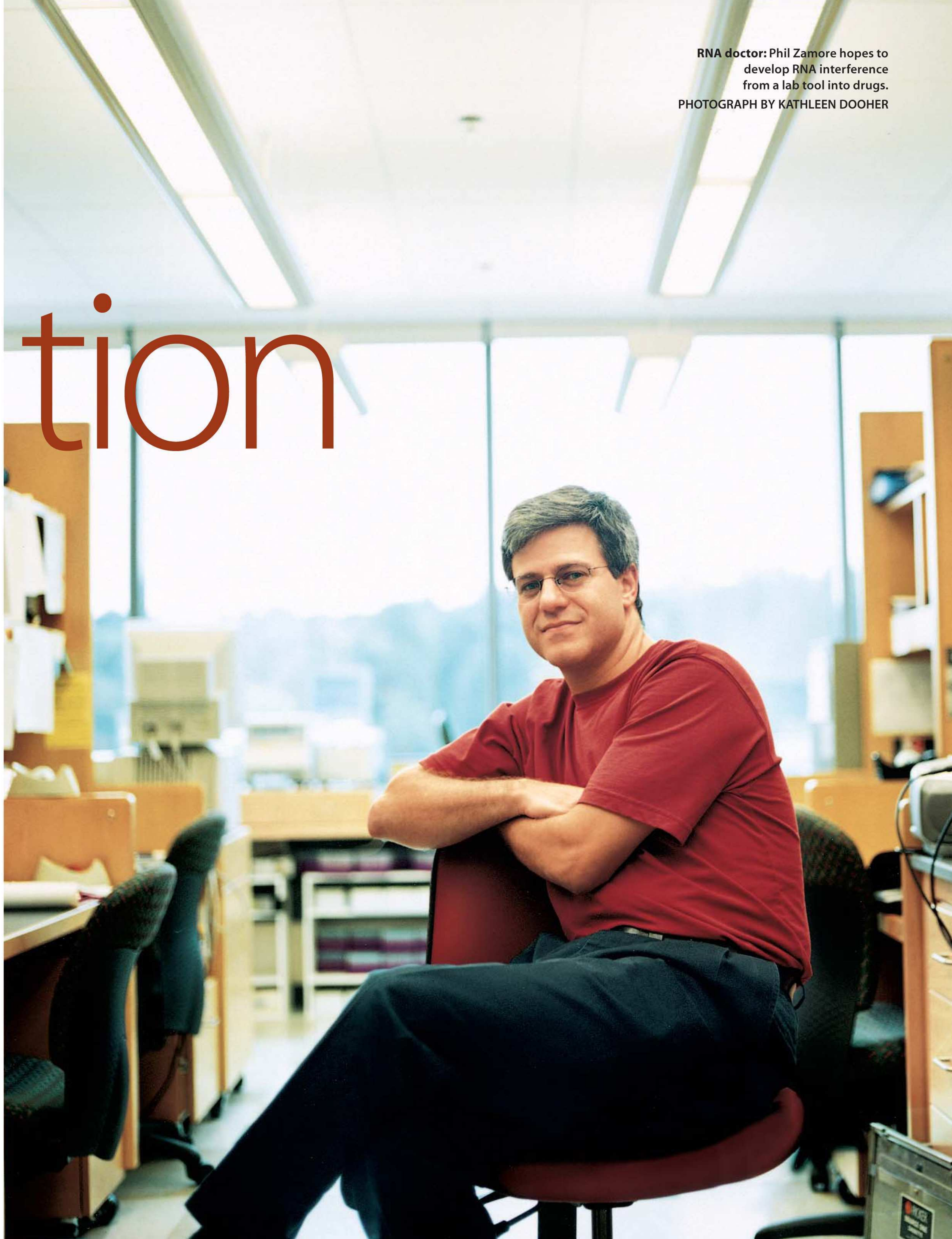
Three technologies in which immobots are already taking hold—spacecraft, copiers, and cars—are roughly on the same size scale as the human body. But as Struss is demonstrating in another project, there's nothing preventing immobots from tackling challenges much larger in size and scope.

In Porto Alegre, Brazil, an industrial metropolis with a population of about 1.3 million, the water utility lacks qualified operators to run all five of the city's water treatment plants. Struss says that many of "the people looking after the drinking water have limited education about how to do that." To support the operators, Struss and his university colleagues are collaborating with the utility to build an advisory immobot that will monitor such water quality measures as turbidity, color, acidity, and alkalinity. The goal is to spot trouble as early as possible and automatically propose therapies.

Although making water safe for human consumption may seem a simple matter, Struss says that it is much more difficult to translate that task into models than it is to deal with the workings of an automobile. That's because a reservoir is more an ecosystem than a machine, and that means that modeling "cannot be limited to looking for faulty components, but [must also look for] unanticipated influences and interactions," he explains.

If there's a change in sensor readings, for example, an immobot-controlled water-treatment plant can reason its way back to the most likely cause only if it has enough interlinked models of the physical and biological processes that affect water quality. Say the water's concentration of iron is hazardously high. The system should hypothesize that an algal bloom is to blame because dying algae change the acidity of water, which in turn redissolves iron in the sediments. Ideally, under such conditions, the immobot would advise operators about short-term

RNA doctor: Phil Zamore hopes to develop RNA interference from a lab tool into drugs.
PHOTOGRAPH BY KATHLEEN DOOHER



BY KEN GARBER

# Prescription RNA

BIOLOGISTS HAVE DISCOVERED AN ASTONISHINGLY EFFECTIVE WAY TO TURN OFF GENES. THE APPROACH USES SHORT PIECES OF RNA AND HAS ALREADY REVOLUTIONIZED DRUG RESEARCH. NOW RESEARCHERS ARE RACING TO MAKE RNA MEDICINES THAT COULD TREAT EVERYTHING FROM CANCER TO AIDS.

It's champagne for everybody. Phil Zamore pops the cork from a bottle of Montaudon, drenching the brand-new carpet. Everyone in his lab fills a glass to toast the boss. "Unexpected good news," he explains. Zamore, a biochemist at the University of Massachusetts Medical School in Worcester, has just received a national award worth $1 million over five years. "The budget of the lab just tripled."

Zamore is understandably giddy, and it's not just about the money. Zamore's field, RNA interference, or RNAi, is only a few years old, but it has taken the world of biology by storm. "RNAi is the most exciting insight in biology in the past decade or two," says Nobel laureate Phillip Sharp, a biologist at MIT. And Zamore's lab is one of a handful moving the field forward at a dizzying pace. "I think everybody who works in the field feels a bit breathless from the progress," Zamore says.

The sense of excitement shared by Zamore, Sharp, and other researchers is well-founded. For decades, researchers thought RNA was merely DNA's messenger, slavishly delivering DNA's protein blueprints. But it now appears that tiny double strands of RNA, introduced into lab-grown cells or animals, can quickly and efficiently turn off any given gene.

The implications are breathtaking, because living organisms are largely defined by the exquisitely orchestrated switching on and off of genes. Biologists, until now, have only been able to mimic this switching process in a slow, ponderous, and indirect way. But the ease with which RNAi can turn off genes, researchers say, seems almost mystical. Laboratory techniques using RNAi are already biologists' methods of choice for discovering the functions of particular genes. And it promises a new way to treat disease directly by shutting down key genes involved in various ailments. Already, at least eight companies—including one founded by Zamore, Sharp, and colleagues—are working on RNAi therapies for everything from viral diseases to cancer.

"The Holy Grail is to develop all this into drugs," says Zamore. "To be able to give you a small interfering RNA that would shut off expression of your high-cholesterol gene. That would lower the level of hepatitis C infecting your liver. Or maybe, I think in perhaps the biggest pie-in-the-sky application, that would hone in on a gene specific to tumor cells and kill the tumor."

"THE HOLY GRAIL IS TO DEVELOP RNAi INTO DRUGS—TO GIVE YOU A SMALL INTERFERING RNA THAT WOULD SHUT OFF YOUR HIGH-CHOLESTEROL GENE OR KILL YOUR TUMOR."

How soon this might happen is anybody's guess. RNA interference burst into the consciousness of the scientific world at the annual meeting of the RNA Society in Banff, Alberta, in May 2001. There, Sayda Elbashir, a postdoc in the lab of biochemist Thomas Tuschl at the Max Planck Institute for Biophysical Chemistry in Göttingen, Germany, stunned his listeners with the news that tiny double-stranded RNA fragments quickly, easily, and specifically turned off genes in human cells, a role researchers had never before seen RNA play.

"Most of the audience was just sitting there saying to themselves, 'Science has just changed,'" recalls University of Michigan biochemist David Engelke. "The only thing that prevented pandemonium was that we'd been promised this sort of thing before." Skeptical, Engelke waited a few months. "Then these reports started to trickle in: 'Gee, this really works!'"

## The RNA Surprise

Until recently, the rather unglamorous role biologists had attributed to RNA was that of a passive messenger, delivering genetic information from DNA to the protein-making machinery of the cell. In this process, the DNA code of a gene is transcribed into an RNA copy, which the cellular machinery translates into a protein. In RNA interference, short bits of RNA block the process by destroying the message en route. The double-stranded RNA fragments lead cutting enzymes to the RNA that carries the genetic message. The messenger RNA is then chopped up and marked for destruction: the gene's message is effectively "silenced."

Biologists have known for years that single-stranded RNA molecules designed to pair with a messenger RNA could shut down protein production, but this artificial process is unreliable even in the lab. Nature, though, does regulate genes using RNA, specifically double-stranded molecules.

The first hints of the phenomenon appeared back in 1990, but at the time, researchers didn't connect what they had observed with RNA. That year, plant biologist Rich Jorgensen, then at DNA Plant Technology in Oakland, CA, was trying to make purple petunias a deeper shade of purple. He inserted a new, supercharged copy of the gene that controls production of purple pigment. To his surprise, he got white petunias. Jorgensen recognized the importance of this paradoxical effect, but he could not explain why adding more of a gene had turned that gene off.

The next clue came in 1995, when geneticists at Cornell University cloned a gene in the microscopic soil worm *C. elegans.* To verify their discovery, they used a standard lab method to turn the gene off: they added a single strand of RNA that matched the messenger RNA. This complementary strand bound to the messenger, stopping it from being translated into a protein. Unexpectedly, a noncomplementary single strand of RNA they were using as an experimental control and which should have done nothing, also shut down the gene.

In 1998 biochemist Andrew Fire, then at the Carnegie Institution of Washington, and geneticist Craig Mello, at the University of Massachusetts Medical School, solved the mystery. Injecting complementary single strands of RNA into worms, they got an astonishingly potent silencing effect when the two strands combined. After demonstrating that double-stranded RNA was the real silencing agent, Fire and Mello coined the term "RNA interference," and a new field was born. In retrospect, Jorgensen's supercharged purple genes yielded double-stranded RNAs that had the same effect on the native purple genes, essentially shutting them off.

The double-stranded RNA seemed to provide a more stable and reliable means for shutting off specific genes than did the single strands, and labs that were studying organisms including plants, worms, and flies eagerly adopted the new method. RNA interference didn't work in mammals, though: the immune system destroys cells that contain double-stranded RNA to defend against RNA viruses like those that cause hepatitis A and C. Then came Tuschl and Elbashir's revelation in Banff that very short RNA segments, which they dubbed "small interfering RNA," did work in human cells. At that point, says Sharp, "the whole field took off."

## Silent Treatment

Now investigators are looking for ways to turn this powerful new role for RNA into corporate profits. Virtually all drug companies already use RNA interference as a tool for drug discovery. One of the most popular strategies for finding new drug targets involves knocking out—or disabling—genes one by one to see what

**Sensible skeptic:** Antisense researcher Frank Bennett believes it could take a decade to develop RNAi-based drugs.
PHOTOGRAPH BY DAVE LAURIDSEN

happens. If, for example, a diseased animal can be cured by knocking out a particular gene, that gene's protein could make a good drug target. Using small interfering RNAs, it turns out, can radically speed this process. Instead of spending months or years to engineer a knockout, researchers use the RNAs to specifically and rapidly shut off a gene. They can also observe whether turning off the protein—as a drug would—causes side effects. The process takes place "in a matter of days, instead of a year," says Christophe Echeverri, CEO of Cenix BioScience, a biotech company in Dresden, Germany.

In the ultimate application, small interfering RNAs might themselves be drugs: rather than blocking a particular protein, as standard drugs do, RNAi would prevent the protein from ever being made. Last June, MIT's Sharp showed that such RNAs, targeted to key viral and human genes, could stop HIV infection in cells grown in the lab. In one experiment, the researchers mixed HIV-infected cells with small interfering RNAs targeted to viral genes. The RNAs halted viral reproduction. Sharp's group also mixed uninfected cells with small interfering RNAs targeted to CD4, a protein on the surface of cells through which HIV gains entry. The researchers showed that the RNAs did decrease production of CD4. Two and a half days later, they exposed RNA-treated cells and untreated cells to HIV. The virus infected four times as many untreated cells.

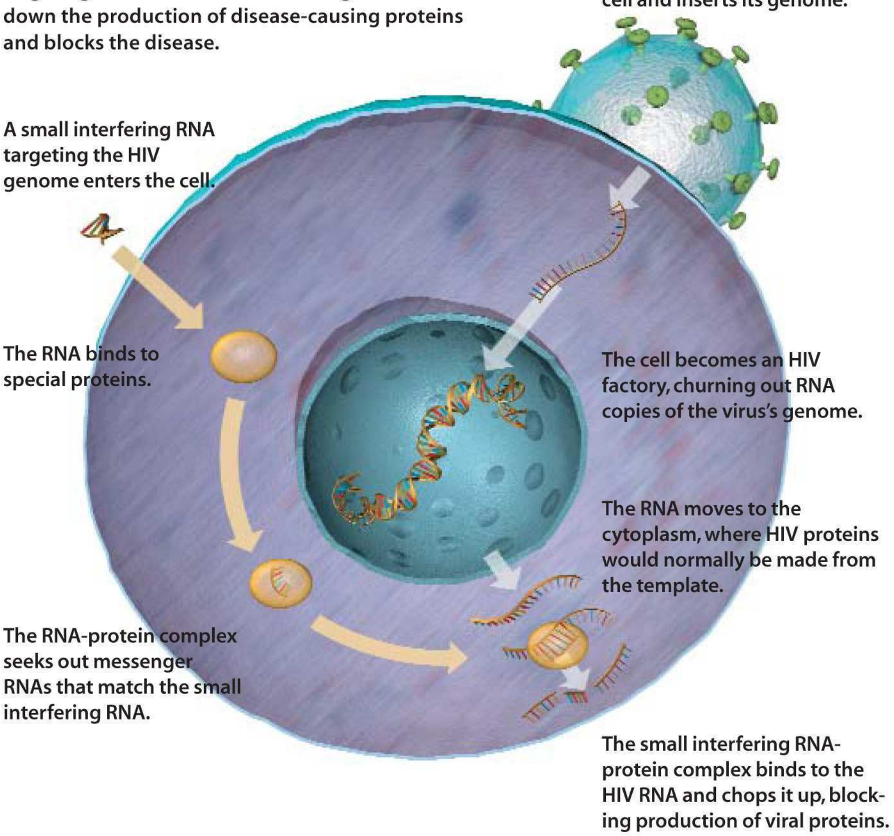
Despite the encouraging results, for the time being RNAi drugs are still in the dream stage, says Sharp. But Sharp considered the early promise tantalizing enough to cofound—with Zamore, Tuschl, and two other scientists—Alnylam Pharmaceuticals in Cambridge, MA, to develop such drugs. The company was barely off the ground when it secured $17 million in venture capital funding last July.

Making RNAi drugs, though, won't be easy. For one thing, no one has found methods suitable for administering the RNAs to humans. "There's a delivery problem. It's as simple as that," says Harvard University chemist Stuart Schreiber. "Getting nucleic acids to their target tissues [is] an unsolved problem in medicine." RNAi therapy is essentially gene therapy, Schreiber says, and it will face the same problems—inefficiency, ineffectiveness, and immunological side effects—that have stalled that field since 1999, when Jesse Gelsinger died during a gene therapy trial at the University of Pennsylvania. Doctors there used modified viruses as delivery vehicles, or "vectors," to shuttle DNA into the teenager's cells. Gelsinger's immune system responded massively—and fatally.

Sharp says the hope is that small interfering RNA might not need vectors to reach its target, thus avoiding most of the pitfalls associated with DNA-based gene therapy. But that scenario is far from certain. "Can you modify RNAs to make them more stable [and] to make them be taken up more efficiently by cells?" Sharp asks. "We don't know."

## Disease Interrupted

**RNAi could be used to treat diseases like HIV/AIDS: targeting the destruction of messenger RNAs shuts down the production of disease-causing proteins and blocks the disease.**




JOHN MACNEILL (INFOGRAPHIC)

## Making Sense

Recent biomedical history doesn't help settle the uncertainty. In fact, this isn't the first time scientists have tried to make a drug based on silencing RNA. Single-stranded "antisense" RNA or DNA can also shut down genes—and doesn't need a vector. Inside the cell, an antisense molecule finds its complementary messenger RNA and, like two sides of a zipper, they bind tightly, preventing the messenger RNA from going through the protein-making machinery of the cell. The result, in theory at least, is gene shutdown.

Antisense, though, has so far been a disappointment as the basis for new drugs. After more than a decade of intense developmental work, only one antisense drug—Isis Pharmaceuticals' Vitravene, for the treatment of certain rare eye infections in AIDS patients—has won Food and Drug Administration approval. The first generation of antisense drugs, which were tested in the early 1990s, rapidly degraded in the body, were hard to get into cells, often failed to find their target, and caused severe side effects. More stable antisense drugs are now being tested in humans.

Can RNAi do better than antisense? Not anytime soon, predicts Frank Bennett, vice president for antisense research at Isis. "If you compare RNAi to the current version of antisense, there really is no advantage," he says. "[Small interfering] RNA technology is really in

**Lab partners:** Roland Kreutzer and Stefan Limmer quit their university jobs to found RNAi startup Ribopharma in Kulmbach, Germany.
PHOTOGRAPH BY PETER BLAKELY CORBIS/SABA

its infancy. It's somewhat equivalent to where antisense was 10 years ago, when we were just beginning to do experiments in animals."

But RNAi people see their technology as fundamentally different from antisense. "The big advantage here of RNAi over antisense is that, lo and behold, this actually really works," says Cenix CEO Echeverri. RNAi, he says, is far more potent and reliable than antisense. "Antisense projects were typically seen as suicide projects," he says. "You could spend a lot of time getting it to work, and it would never work. You'd be left with nothing to show." RNAi's greater potency, Echeverri believes, should yield better therapies. And because less drug will be needed to silence a gene, there should be fewer side effects.

"People have been struggling with antisense, and here's a technology that comes along that really works," agrees Jon Wolff, chief scientific officer of Mirus, an RNA therapeutics company in Madison, WI. "Antisense is hard to reproduce, but RNAi is something that works right out of the barrel."

But could RNAi be just another overhyped technology? "The proof is in the pudding," says Echeverri. "Over the last two, three years, RNAi has just completely taken over. Everyone is turning to it; in every organism they're trying it. And it wouldn't be this popular if it weren't successful."

## Silencing Doubts

No one has yet tried RNAi in humans, but one company is close: Ribopharma, a biotech startup in Kulmbach, Germany. More than a year before Tuschl's group stunned the scientific community with its news, Ribopharma's founders, former Bayreuth University lecturers Roland Kreutzer and Stefan Limmer, discovered that small RNAs worked in mammalian cells. Or so Kreutzer and Limmer claim. They have never published their data.

Kreutzer and Limmer reasoned that it was physically impossible for the very long RNAs, such as those used by Fire and Mello, to bind all at once to their target RNAs. Only short segments would stick. So they tried silencing mammalian genes using RNAs short enough to evade the fatal immune response. "It was…gambling," says Limmer. "And it turned out that it really works." The researchers filed a patent application, quit their teaching jobs, and in June 2000 founded Ribopharma.

Ribopharma's principals are planning to begin human trials next year, probably starting with tests of small interfering RNAs in the treatment of malignant melanoma and pancreatic cancer. Kreutzer and Limmer say their RNA constructs are stable enough to work without vectors and can be injected directly into the site of a tumor or into the bloodstream. The company has raised more than $18 million. But because Ribopharma has yet to publish its results, it's difficult to evaluate its claims, say other RNA researchers. "They've been doing some things," says MIT's Sharp, "quite nicely....[But] it's a long road."

How long? Attitudes range from Ribopharma's sanguine assurances to strong pessimism. David Beach, president of RNAi startup Genetica in Cambridge, MA, points to antisense's decade-plus odyssey. "I don't want to sit and argue deploying RNAi in a therapeutic mode would be any simpler," he says.

What is far clearer is that RNAi is forcing biologists to rethink RNA's role. In the last few years, researchers have found hundreds of genes that code for small RNA molecules, dubbed "microRNAs," in organisms ranging from plants and worms to humans. Like their small interfering RNA cousins, microRNAs appear to silence genes, but their role in biology is mostly unknown. "Many of them have been very highly conserved during the course of evolution; [so] they must be doing something important," says MIT biologist David Bartel. Meanwhile, the realization that RNAi is a natural—and probably fundamental—process in plants and animals has helped make it one of the most exciting mysteries in today's biology.

"Tiny RNA genes may be the biological equivalent of dark matter—all around us but almost escaping detection," wrote Gary Ruvkun, a Harvard Medical School molecular biologist, in 2001 in the journal *Science*. What are these mysterious genes doing? "I suspect what we're looking at is a very ancient method of controlling gene expression," says Zamore.

If microRNAs are switches that decide whether stem cells become neurons or muscle, or whether cancer cells grow or die, then RNA interference is a lot more important than anyone imagined just a few years ago. "We simply stumbled upon a whole new branch of molecular biology that we didn't know about before," says Michigan's Engelke.

To the optimists, these breakthroughs portend the quick development of effective drugs. And even biomedical researchers made cynical by extravagant claims for magical cures think RNAi just may be the real thing. Last year, when RNAi first worked in human cells, "everyone woke up and said, 'I wonder if this is the silver bullet?'" says Engelke. "And it might be. It might be." TR

## Companies Developing RNA Interference

| COMPANY | PRIMARY RNAi FOCUS |
|---|---|
| **Alnylam Pharmaceuticals (Cambridge, MA)** | Therapeutics |
| **Benitec (Brisbane, Australia)** | Intellectual property for genomics and therapeutics |
| **Cenix BioScience (Dresden, Germany)** | Drug target identification and therapeutics for cancer |
| **Devgen (Ghent, Belgium)** | Drug target identification and therapeutics for diabetes, depression, and Parkinson's disease |
| **Genetica (Cambridge, MA)** | Drug target identification for cancer |
| **Mirus (Madison, WI)** | Therapeutics, using long double-stranded RNA |
| **Ribopharma (Kulmbach, Germany)** | Therapeutics for cancer and hepatitis C |

**Fare game:** Subway riders in Washington use smart cards equipped with a memory chip and radio transponder.


Smart cards, radio tags, and microchip buttons are going to revolutionize the way you buy things. By Evan I. Schwartz

**PHOTOGRAPHS BY FURNALD/GRAY**

# how you'll pay

To catch the future of payment schemes, go underground. Beneath the streets of the nation's capital, more than 60 percent of peak-time riders on the Metro (Washington, DC's subway network) have switched from magnetic-stripe tickets to "smart cards" embedded with memory chips and radio transponders. Riders can load as much as $200 into their SmarTrip cards at a kiosk or over the Internet. Antennae built into subway turnstiles pick up radio signals from the cards and convert them into streams of bits that denote the embarkation point and subtract money from the card's memory. Similar systems are being planned for other U.S. cities, and next year London will adopt these newfangled fare cards for its famous double-decker buses and massive Underground subway network.

But the ultimate destiny of such electronic-payment devices goes way beyond multibillion-dollar public-transit projects. Smart cards and rival gadgets are rapidly evolving into technology platforms that could trigger changes in everything from urban commerce and suburban shopping sprees to national security. Commuters could eventually use such devices not only to buy coffee and newspapers, but also to store bus transfers, hold medical records and drug prescriptions, download coupons, and redeem tickets to museums and sporting events. "The current thrust is to reduce or eliminate the cash handled by these fare collection systems," says David de Kozan, vice president of market planning and support at San Diego-based Cubic Transportation Systems, which supplies cards and readers to the Washington and London transit networks. "But the technology can also provide other tools. You could rent out spaces on the card for different applications."

And so the competition to produce and popularize the most secure, the most convenient, and the most versatile high-tech payment system is heating up. One contestant in this race is indeed the smart card, which incorporates not only a memory chip but also a microprocessor. Touted for more than a decade and already popular in Europe, the cards have yet to make it big in the United States, Washington's Metro notwithstanding. Meanwhile, radio wave transponder tags that supply identification data, as well as coin-size microprocessors that store security codes and encrypted money are gaining ground.

The merchants, banks, and device manufacturers that figure out and deliver what people want from these technologies stand to reap a rich bounty of profits and transaction fees on the $5.7 trillion in annual credit- and debit-card purchasing worldwide—not to mention tens of billions of dollars more in the market for secure identification, subway payment, and other applications.

It won't be easy. Credit card companies and banks have long pined for a large-scale rollout of microchip-based payment devices mainly because storing customers' identity data on chips has proved a more secure and reliable way to prevent fraud than encoding data on a traditional magnetic stripe. And because consumers are not liable for transactions conducted using their stolen identities, merchants and banks eat the estimated $4 billion in annual losses. In high-profile tests—most notably Visa's trial at the 1996 Olympic Games in Atlanta and a 1998 Citibank and Chase Manhattan experiment on Manhattan's Upper West Side—stored-value smart cards have been resounding flops. Not only that, the costs of implementing a new system are formidable. Diana Knox, senior vice president of emerging channels at Visa U.S.A., estimates that it would cost $11 billion to replace magnetic-stripe cards and upgrade U.S. authorization terminals and networks. "The infrastructure hurdles are enormous, and there isn't much money in processing small transactions," Knox says.

**MERCHANTS, BANKS, AND DEVICE MAKERS THAT FIGURE OUT THE BEST PAYMENT TECHNOLOGIES WILL REAP A RICH BOUNTY FROM THE $5.7 TRILLION IN ANNUAL CREDIT- AND DEBIT-CARD TRANSACTIONS**

That is why smart cards have for years been a technology in search of compelling applications. Yet it is a quest that is quickly gaining new urgency—and not just beneath the streets of Washington and London. Retailers such as Target Stores are introducing smart cards that can receive and redeem digital coupons and other incentives. And over the next few years, the credit card industry will mandate that many European, Asian, and Latin American countries replace magnetic-stripe credit cards with smart cards. Toni Merschen, senior vice president for chip and mobile commerce at MasterCard International's laboratory in Waterloo, Belgium, says, "We have a big global migration ahead of us."

## Smarter Cards

The potential of the smart card to handle many different applications has revived hopes for making the technology as commonplace in the United States as it is becoming overseas. Advances in the technology itself are driving the possibilities in the marketplace. Three years ago smart cards boasted the processing power of a 1980 Apple II computer; today's versions are approaching the level of a 386-class PC, circa 1990. Most smart cards can hold 32 kilobytes of data, and their embedded microprocessors can execute simple application programs stored in 64 kilobytes of flash memory.

That's enough computing power to run multiple payment, customer loyalty, health-care, and security applications on a single card. "It is essentially a PC without the keyboard or display," says Neville Pattinson, director of business development for New York City–based SchlumbergerSema, a top maker of microprocessor cards. The cost has dropped below $5 apiece for quantities of thousands, and smart cards with the power of a Pentium-class PC are within reach this decade, he says.

Perhaps the biggest push for smart cards is coming from large organizations that want them for their employees. In one of the largest smart-card rollouts under way, the U.S. Department of Defense is issuing a Common Access Card to every member of the armed services. Each card includes a photograph and a microchip that authenticates identity whenever the card holder enters an agency facility or logs onto its computer network. The card will also encrypt and


**Faster fill-ups:** ExxonMobil's Speedpass transmits a customer's information to a gas pump or checkout register, which bills her credit card.

decode employees' e-mail. More than a million of these cards have been deployed, and the department plans to issue the cards to all its 3.5 million officers, service members, and civilian employees within the next year.

Prompted in part by the security concerns that crystallized after September 11, other government agencies are following suit. The Aviation and Transportation Security Act and other recent legislation mandate that the Department of Transportation, the Border Patrol, and other agencies investigate a universal worker-identification device that would hold biometric data such as fingerprints and digital "faceprints." The devices would be automatically monitored at checkpoints or spot-checked by roving security officials. Workers may need the cards to log onto agency and airport computer networks, as well as to gain physical entry into facilities. "Post-September 11, there are secure-identification projects going on all around the world," says Ed MacBeth, senior vice president of marketing at ActivCard, a Fremont, CA, company that is supplying software for the Defense Department's card. "The card has to be smart enough to identify the user," MacBeth says. "It's no longer good enough just to flash a photo ID."

Although government agencies are rolling out the largest number of cards, the technology is turning up at major corporations, as well as college campuses and other large institutions. Hewlett-Packard, Microsoft, and Sun Microsystems are all issuing cards to tens of thousands of employees for building access and for logging into their corporate computer networks. Some employers are enhancing cards with such applications as electronic-cash accounts that can be used at their company cafeterias. Managing the cards is getting so complicated that companies are contracting the work out to banks.

## Paying by Waving

But are smart cards too smart for their own good? Developers of technologies that compete with smart cards argue that it's precisely the complexity of those cards that will spell their doom in the marketplace. For such everyday applications as buying gasoline, smart cards may be impractical: they require new equipment and authorization procedures. "We've been hearing the pitch about smart cards for 10 years," says Joe Giordano, a business development vice president at ExxonMobil. "But there isn't a need for the technology unless it has a real benefit for the consumer."

That's what prompted Giordano to develop an alternative technology for streamlining the purchase of gasoline. Brainstorming on an airplane trip nearly 10 years ago, he sketched a simple payment idea on some cocktail napkins on his tray table. He envisioned a toe-size device that would hang on a key chain. "It needed to be durable, reliable, simple, and lightweight," Giordano recalls thinking at the time. Wave it in front of a gas pump, and a customer's identification code would be picked up from the device's built-in radio transponder. A customer would no longer have to find her wallet, pull out her credit card, and swipe it through a reader. Before Giordano got off the plane, he had even come up with a name for this device: Speedpass.

Giordano successfully sold the idea in a series of corporate strategy meetings. Nearly six million people now use the Speedpass, and the payment system has been installed at more than 7,500 Exxon and Mobil service stations. Unlike the smart card, Speedpass has no onboard computer chip or memory. It consists of a radio transponder programmed to transmit a digital code that identifies its user. A radio receiver inside the gas pump constantly scouts the immediate airwaves for the presence of a Speedpass, and when it finds one, it simply picks up the code numbers that authorize payment from the customer's credit card. (Similar radio tags are embedded in the FastLane, FasTrak, and E-Zpass units millions of U.S. motorists use to pay highway tolls.)

ExxonMobil is now taking this simple message to other retailers. Giordano, cur-

## Digital Payment's Big Three

| | MAKERS | APPLICATIONS | STORED INFORMATION | DEVICE TALKS TO READER | READER TALKS TO NETWORK |
|---|---|---|---|---|---|
| Smart card | **SchlumbergerSema** (New York, NY)<br>**Gemplus** (Gemenos, France) | Customer loyalty program at Target Stores | Personal-identification data; programs that formulate special offers, discounts, and loyalty certificates | Swiped through a checkout counter reader, a card's embedded microprocessor communicates via its gold-plated contact pad. | Transactions are authorized via data lines, and purchasing information used to formulate loyalty offers is uploaded to the store's database. |
| Speedpass | **ExxonMobil Speedpass Network** (Fairfax, VA) | McDonald's drive-through service | Customer's identification code | A radio transmitter inside the McDonald's order box signals a nearby Speedpass transponder to emit its unique identification code. | The unique code and purchase amount are sent over the standard credit-card authorization network. |
| iButton | **Dallas Semiconductor** (Dallas, TX) | Canadian vending machines | Digital-cash accounts | When an iButton is touched to a vending machine's receptor, the sale is debited from the chip's memory. | The self-contained system does not communicate with any network. |
| | | Segway starter key | Vehicle identification data and codes for controlling top speed and steering sensitivity | Touching the Segway key to the receptor on the handlebar identifies the driver and adjusts the vehicle's settings. | The self-contained system does not communicate with any network. |

rently vice president of the company's Speedpass Network unit, is signing deals with fast-food restaurants and grocery stores. The Speedpass is being tested in Chicago-area McDonald's restaurants and at Stop and Shop supermarkets around Boston. At a McDonald's restaurant, the reader is incorporated into the drive-through order box. At Stop and Shop, Speedpass readers are built into automatic teller machines in special checkout lanes. In addition, Giordano has signed a deal with Timex to build the devices into watches that will be available in 2003. The goal, he says, is to make Speedpass a "ubiquitous form of customer ID and payment."

## Button-Down Solution

The wild card in the electronic-payment competition against smart cards comes in a smaller package. The iButton—a 16-millimeter diameter steel canister containing a microchip—has advantages over both technologies. The iButtons, made by Dallas Semiconductor, are activated when they are placed in contact with a receptor pad on, say, a vending machine. As soon as it touches the pad, the iButton transmits data directly to the chip inside the receptor. The device can be made into a ring, worn on a necklace, or built into a wide array of garments, says Dallas Semiconductor vice president Michael Bolan, iButton's coinventor.

Unlike a Speedpass, which stores nothing but the user's identification code, an iButton can hold electronic cash, coupons, and other data. In that sense, it does resemble a smart card, but Dallas Semiconductor claims that the steel button is more rugged than the plastic card. And cheaper, too: Bolan says that his company supplies the devices for less than $1 each in large quantities. By contrast, SchlumbergerSema's Pattinson confirms that smart cards typically cost at least $4 each.

In addition, because the iButton isn't a major-brand credit card, there are no transaction fees, which range from two to six percent of every MasterCard, Visa, or American Express payment. The iButton's chief drawback is that, unlike other payment technologies, it adheres to no recognized standard: it stores and communicates data in a proprietary format.

In iButton's most extensive installation so far, it serves as a subway pass in Istanbul, Turkey. Riders entering the station simply touch their buttons to a reader, which deducts the payment from electronic cash stored on the button. Five million people now use the so-called Istanbul Purse, which is also gaining acceptance as a form of payment among the city's merchants.

All told, according to Dallas Semiconductor, there are more than 65 million iButtons in use worldwide. That includes large installations in parking meters in Brazil and Argentina, gas stations in Moscow and Mexico City, bus terminals in China, hospitals in Switzerland, apartment buildings in Korea, and vending machines in Canada.

One application should drive that number even higher. Dean Kamen, inventor of the self-balancing Segway electric scooter, which is expected to hit the market in 2003, has selected the iButton as the Segway's all-purpose starter key and security device. To activate the vehicle, the user touches the steel canister, mounted on a key-size piece of plastic, against small metal contacts on the handlebar. The Segway owner can program the chip with a variety of access features, including top speed and steering sensitivity. Companies with Segway fleets can use that ability to control their users' driving behavior.

**THE 65 MILLION iBUTTONS IN USE PAY FOR SUBWAYS IN INSTANBUL, PARKING METERS IN SOUTH AMERICA, AND VENDING MACHINES IN CANADA. UP NEXT: TURNING ON THE SEGWAY.**

## Fraud Busters

Although most Americans have yet to encounter any of these portable payment and identification devices, the technologies are proliferating throughout the rest of the world. Smart cards were introduced more than a decade ago, and in the past few years they have gained real momentum; more than 685 million smart cards were shipped last year alone, 60 percent of them going to Europe and 30 percent to Asia, according to Gartner Group, a market research firm in Stamford, CT. "My colleagues from the States think it's hilarious," says Clare Hirst, a London-based analyst with Gartner. "They come over here and say, 'you've got chip cards for everything.'"

Most of the smart cards in Europe are postage stamp-size SIMs, or subscriber identity modules, that give a mobile-phone owner the option of requiring a password for placing calls. These cards, which large numbers of Europeans have been using for a decade, not only store identity data but also hold phone numbers, address lists, and other personal information. Users can pop their cards into new phones, retain all their collected data, and begin charging calls to their own accounts. Due to the far lower incidence of telephone fraud in the United States, U.S. phone companies have been policing scams only after they have happened. Thus, Americans are just starting to gain experience with chip card technology already familiar to Europeans.

Europeans have deep-seated reasons for their devotion to stopping fraud and their rapid adoption of smart cards. Because government-owned telecommunications companies have precluded a competitive business environment in Europe, even local calls are expensive. "There is no such thing as a free local call in Europe," says Pattinson, of SchlumbergerSema. To reduce telecommunications costs, European merchants process credit card transactions in batches rather than individually in real time, the standard practice in the United States. By the time European merchants check authorization, the thieves have made their getaway. It's simple for store clerks and waiters to "clone" credit cards: they quickly skim the data from magnetic-stripe credit cards and transfer the information to new cards for use somewhere else. This procedure makes it easier for thieves using stolen or cloned cards.

Smart cards go a long way toward thwarting such popular crimes, and they save European retailers a bundle: because the money is in memory, there is no need for costly phone-based verification. Before the introduction of smart cards in Europe, card cloning and theft resulted in fraud rates as much as 10 times higher

than those in the United States, says MasterCard's Merschen. Key features of today's smart cards were invented in France in the mid-1970s to combat this very problem. "It's easy to hack into a card with a mag stripe," says Peter Buhler, manager of IBM's Secure Systems Research Group in Zürich, Switzerland. "Smart card chips are resistant to tampering."

Europe is now going one step further. The Europay-MasterCard-Visa global consortium, or EMV, has set a series of deadlines by which all banks in Europe and many parts of Asia and Latin America must issue smart cards to their customers. By 2005 the switch to smart cards should be complete in many countries. Though its edict lacks the force of law, the consortium can use strong financial incentives and punishments to impose nearly universal acceptance. "EMV has said it will no longer absorb the cost of fraud in those regions," says Gartner's Hirst. "So if they don't comply, the banks and merchants will have to take on the cost of the fraud themselves."

This liability transfer is "the ultimate enforcement measure," says Visa's Knox, who notes that there will be "real financial consequences for those who fail to adopt smart cards." The cost of moving so many banks and merchants to smart cards is expected to total billions of dollars, but in much of the world, the antifraud benefit is expected to justify the expense, she says. In the United States, however, where fraud rates are so much lower, the savings reaped from reducing fraud would not justify a comparable action, Knox adds.

Yet the United States could very well be forced to join the global conversion, Gartner's Hirst predicts. "If fraud isn't as easy in other regions, the crime will shift to the U.S.," she says, "or it will look high in comparison." ActivCard's MacBeth agrees. "If the rest of the world deploys smart cards, and that eliminates much of the fraud elsewhere," he says, "the criminals will focus on the United States, and we could become the last bastion of magnetic-stripe fraud." This, he says, would force the United States to replace its infrastructure. "We wouldn't have much of a choice."

## Shopping's Next Wave

Or the current infrastructure could be bypassed altogether. In the future, portable computing devices and smart cards will become one and the same, perhaps lessening the importance of stationary card readers. Diana Knox of Visa says the credit card networks are already experimenting with smart card capabilities in cell phones and handheld computers. Long-advertised scenarios in which a cell phone user zaps money through the air to a vending machine or to a friend's cell phone will become commonplace, she predicts. "At the end of the day," she says, "it's not about the devices as much as it is the payment network. Visa can be inside the phone or inside a personal digital assistant."

That might be wishful thinking. As PayPal, the online payments pioneer, has shown in the fast-growing market for person-to-person payments over the Internet, cost and complexity must be much lower before consumers will accept the technology *(see "Digital Cash Payoff,"* TR *December 2001*). In eBay auctions, PayPal introduced the ability to transfer cash to anyone with an e-mail address. Thus online sellers could accept money from far-flung strangers without opening expensive Visa and MasterCard merchant accounts. Once PayPal struck the right formula, millions of users flocked to the system, providing the critical mass of success that led to eBay's $1.5 billion acquisition of PayPal in October.

**SHOPS COULD TARGET SMART-CARD HOLDERS IN THE VICINITY WITH WIRELESS TRANSMISSIONS THAT PROMOTE DISCOUNTS ON EVERYTHING FROM T-SHIRTS TO BOOKS AND BACKPACKS.**

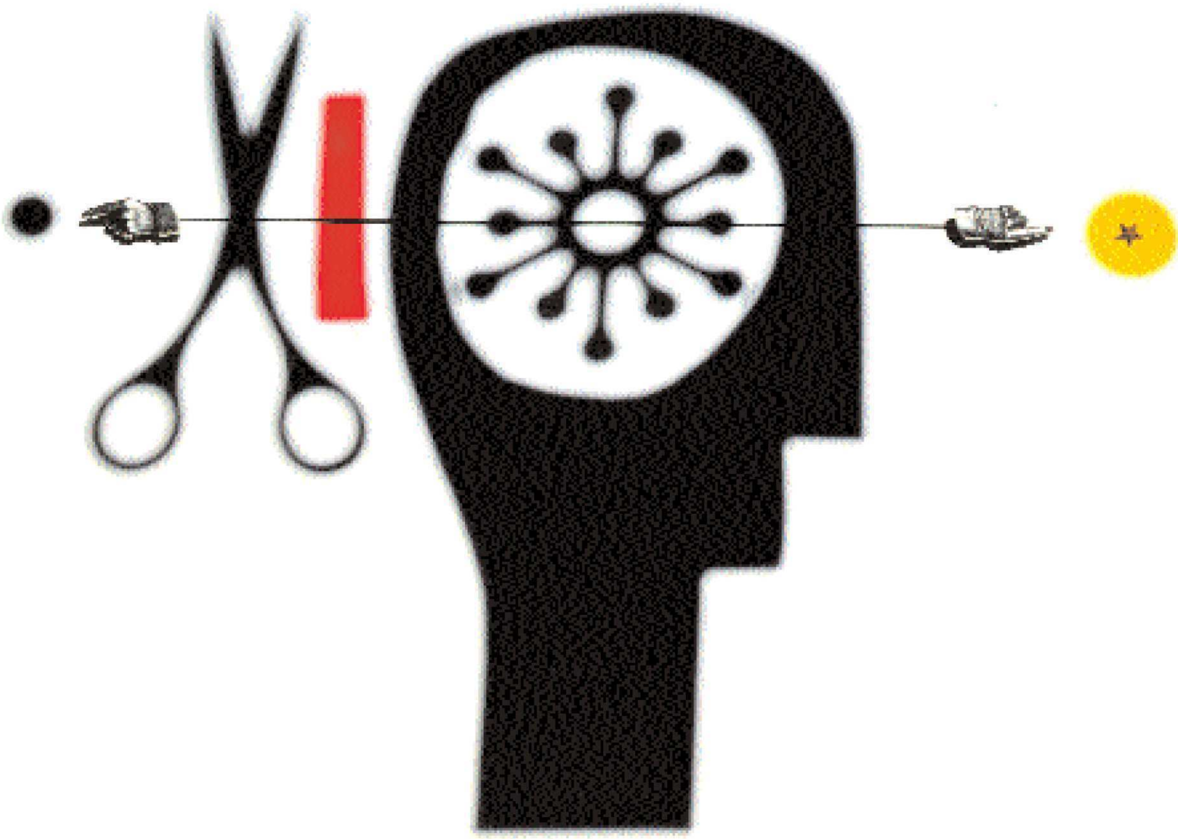
Such rapid market acceptance helps explain why so much energy is now being channeled into finding plausible applications for new payment technologies and why the SmarTrip system in Washington's Metro is considered such an important market test. Another key trial is under way at Target Stores, the third largest U.S. retailer. Target is issuing microprocessor-equipped Visa smart cards to its customers. Checkout lanes with smart-card readers will be programmed to monitor purchasing patterns and load coupons, promotional offers, and loyalty incentives into each card's 16 kilobytes of memory. To better integrate Internet commerce with what happens in its stores, Target is giving free smart-card readers to shoppers, who plug the devices into their home PCs to access a special Web site. Eventually, customers will be able to download electronic coupons and receive new offers. "This is the first test of its kind in the world," says Visa's Knox. "Many merchants are cautiously watching what is happening at Target."

The next wave of applications is bound to bring more creative ideas, says Ted Selker, who heads the MIT Media Lab's context-aware computing group. His experiments have included putting chips in clothing, furniture, and other everyday items. Selker foresees a day when airport shops will target smart-card holders in the vicinity with wireless transmissions that promote discounts on everything from T-shirts to books and backpacks. Another possibility: as a customer approaches a rack of clothing in a store, wireless readers in the clothes hangers glean his size information from the smart card in his wallet, causing lights on the hangers of outfits that are his size to flash. Selker says the goal isn't so much to wow as to figure out "how do you add functions that can simplify people's lives?"

In the meantime, payment devices will assuredly proliferate—to the point that the average person might carry four or five variations of smart cards. No single technology will likely dominate; rather, radio tags, chip buttons, and smart cards will catch on wherever their qualities are best suited. A person might have an iButton for secure access to her apartment building, a Speedpass to buy gasoline and convenience store items, a smart card for riding the subway and storing tickets to events around town, a multiapplication card for corporate access and health-care data, and even a cell phone with a smart chip that can transfer money to the phone of a friend.

Just don't be too surprised to find that your digital fingerprints are floating through the air along with your money. As the payment technologies take off, you'll be able to do just about anything with your smart card or Speedpass or iButton. And then you'll be asking whether you can do anything without them. TR

**Smart as a button:** Touch an iButton to a matching receptor and cash flows electronically from its steel-encased microchip.



# R&D2002

## RESEARCH THAT BREAKS THE MOLD

It is no secret that in tough economic times, corporate spending on research and development often takes a hit. So it should be no surprise that *Technology Review*'s annual survey of R&D expenditures by 150 top public companies reveals a mixed picture.

Spending levels at some of the world's largest research-oriented organizations, including Microsoft and Siemens, continued to rise. But at a number of other companies—particularly those within the economically troubled telecommunications and semiconductor sectors—spending shrank. Our "Corporate R&D Scorecard" shows that the picture is most dismal in telecommunications. The situation was slightly better at top semiconductor manufacturers Intel and Texas Instruments, both of which reported modest cuts in R&D budgets. Corporate frugality extended to other industries as well: a number of the traditional research powerhouses—3M and DuPont, for example—also trimmed budgets.

But statistics never tell the whole story. And although the usual practice in a recession is for companies to focus on short-term incremental advances to existing product lines, *Technology Review* uncovered no shortage of speculative research efforts that, if they succeed, could revolutionize whole industries.

To highlight this point, we have chosen to complement the scorecard with profiles of four high-risk research efforts. These projects, which break the corporate mold of focusing research sharply on existing business and bottom line "results," demonstrate corporate risk taking at its best. At Microsoft, Michael Freedman and his fledgling quantum-computing research group are rethinking the basics of computation; and at General Motors, researchers are exploring advanced fuel-cell designs that could revolutionize the notion of a "car." At General Electric, a nanotechnology group aiming to redesign advanced ceramics is using seashells as its inspiration. And at Hitachi in Japan, researchers are hoping to apply brain-imaging technology to improve how people, including newborn infants, learn.

These investigations cover a broad range of technologies. But they have one feature in common: the ambition to develop disruptive technologies that will transform their companies—and have a lasting impact on the world.

PIERRE-YVES GOAVEC

# QUANTUM COMPUTING

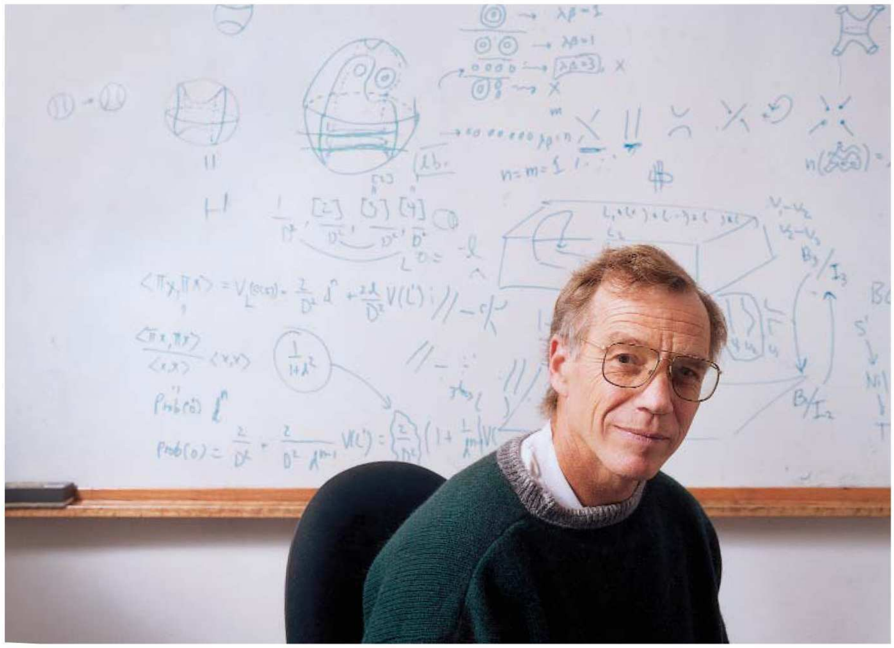
group **Microsoft Research's theoretical mathematics program**
goal **A strategy to make quantum computing work**

Populated by programmers worrying about fixes for the latest operating systems and rollouts of new applications, a software company might seem an odd place for rethinking the very foundations of computation. But at Microsoft Research, Michael Freedman is doing just that. One of the world's most heralded mathematicians and a 1986 winner of the Fields Medal—math's equivalent of a Nobel Prize—Freedman is spending his days pondering one of the toughest puzzles in physics: how to transform quantum computing from an abstract dream into a feasible technology. And he believes he may have found a solution.

For decades, physicists have speculated that quantum computers would define the ultimate limits for speed, size, and power in computers. The peculiar laws of quantum mechanics dictate that a "quantum bit" has almost magical computing potential. While the digital bits stored in a desktop computer correspond to either ones or zeroes, quantum bits—sometimes represented in the spin of nuclei or ions—can be both ones and zeroes simultaneously. Even odder, quantum bits are linked by a phenomenon called "entanglement." Together, these properties mean that a computational operation on one quantum bit affects others, implying potentially awesome computing power. In theory at least, quantum computers will need only microseconds to crack even the most sophisticated encryption codes and will be able to search petabyte databases in a flash.

"The idea is to store a bit of information on each atom," says MIT quantum computer researcher Seth Lloyd. "It's the logical endpoint of Moore's Law."

At this nanoscopic scale, however, the world is anything but logical. For those hoping to build a quantum computer, that is both good and bad, and it's where Freedman's work comes in. Specifically, he's trying to solve a problem that has bedeviled quantum computing researchers seeking a way to store information in the spin of nuclei or ions: even



Michael Freedman believes he has solved one of the toughest problems in quantum computing: how to create quantum bits that can withstand outside disturbances. If his calculations are correct, they could point to the breakthrough that will make quantum computers a reality.

ANDREW MIKSYS

the slightest disturbance scrambles the quantum bits and destroys their entanglement. Topology, Freedman's brand of abstract math, might provide the answer. Topologists worry about the qualities of geometric shapes rather than quantities such as size: the way strands of a knot are entwined is more important than how big the knot is. And Freedman believes that if quantum bits were based on topology, they would be far more robust.

To visualize how this might work, put three marbles on a table and scoot them around. If you were able to keep track of and record the position of the marbles over time, their three paths might eventually trace a "braid." Freedman imagines that his computer would be made of special "quasiparticles" found in exotic materials such as superconductors that "remember" where they have been. These particles might be braided or arranged using electric fields, and the shape of the braid would be used to represent data. Unlike other quantum bits, however, these quantum braids would be less vulnerable to external disturbances because their shapes would be robust.

Freedman's work doesn't stop with out-of-this-world thought experiments. He's looking for a real material that can perform these topological tricks. "I'm a pure mathematician transitioning into materials designer," he says. To help him, Freedman has recruited researchers with materials experience onto his team. Working together, they hope both to design and to fabricate a substance that has all the right properties for supporting error-free quantum computing.

This project, of course, marks quite a departure for Microsoft, a company associated with word processing software and desktop computing—not materials science or basic physics. For one thing, it will likely be decades before quantum computing becomes feasible, if it ever does. And for another, if Freedman is right, his advance will signal a quantum jump in computing that will make almost everything Microsoft does obsolete. "My fantasy," says Freedman, "is that Bill Gates can get up someday and say Microsoft introduced the quantum computer and a software revolution at the same time." — *David Voss*

# ELECTRICITY-PRODUCING VEHICLES

group **General Motors' Hydronomy program**
goal **Fuel cell cars linked to the electric grid by 2010**

When General Motors, the world's largest automaker, attempts to reinvent the world's energy infrastructure—even rethinking notions of the car itself—it's not exactly research as usual. But in recent months, Detroit-based General Motors has integrated and expanded several existing research programs in a concerted effort to provide an alternative to the internal combustion engine. The plan is to use hydrogen to power cars, to tap into the vehicles' idle time to supply residential energy, and eventually to supply the nation's electric grid.

General Motors is pinning its ambitions on fuel cells, which generate electricity through a chemical reaction that starts with hydrogen and emits only water and heat. Other automakers and electricity companies are working on similar fuel-cell technology. Indeed, the first generation of fuel-cell-powered cars will hit the market over the next few years. But Larry Burns, the company's vice president for research, development, and planning, says General Motors is devoting some 600 staffers and "hundreds of millions of dollars" to a far more radical concept for the fuel-cell-powered car in a research program called Hydronomy, shorthand for "hydrogen economy." Burns says, "We think that if this is successful, it will be a much bigger idea than inventing the automobile. It not only reinvents the automobile but our industry."

It is radical because instead of integrating fuel cells into today's car designs, the company plans to manufacture a fuel cell chassis. The skateboard-like platform would be connected electrically to a replaceable body. That way, says Chris Borroni-Bird, director of design and technology fusion, "It could last 20 or 30 years. You could mortgage a chassis like you mortgage your house and just get new bodies instead of new cars." The approach, he says, could help make fuel cell cars far cheaper over the long term and, therefore, more attractive to consumers.

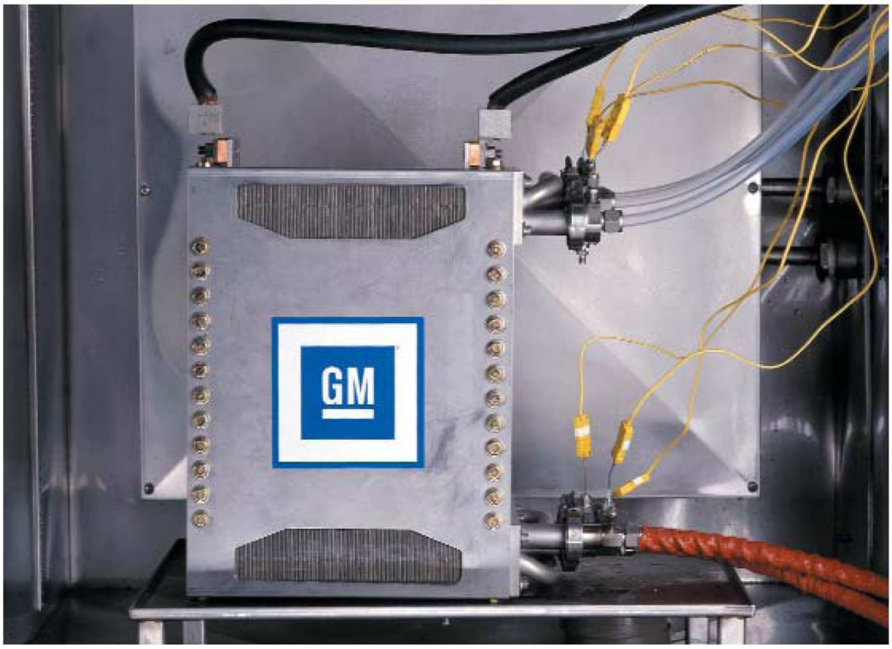
The fuel cell skateboard is the building block of a larger vision as well. The automaker foresees eventually using the fuel cell car for distributed generation of electricity. After all, 90 percent of the time, today's cars sit unused in parking lots, driveways, and garages. A parked fuel-cell car could generate cheap electricity and help supply power to a house or even feed the local electric grid.

Although the technology remains a gamble and its first fuel-cell-powered grid-ready car won't hit the market before 2010, the company has mapped out steps for achieving its goal. In September General Motors snapped a specially designed auto body onto a fuel cell skateboard and unveiled its first drivable prototype. To help accelerate fuel cell development and grid readiness, the auto giant plans to enter the electricity business by 2005 and begin selling stationary fuel cells to supply power to buildings.

To make all this happen, General Motors has corralled research groups in Germany, New York, Michigan, and California into the Hydronomy effort; the project's 600 workers include 100 added in 2002. In one area of emphasis, researchers are developing the electronics for connecting a car to a house or grid. To achieve that objective, in 2002 General Motors added a research group at the company's Advanced Technology Center in Torrance, CA. The electronics are already available for large stationary fuel cells, but the challenge for the Torrance group is to make inexpensive versions small enough for cars. Meanwhile, in Honeoye Falls, NY, company researchers are trying to improve fuel cell efficiency, and they are also working on an affordable and rugged reformer, a device that makes hydrogen from such fuels as natural gas and gasoline.

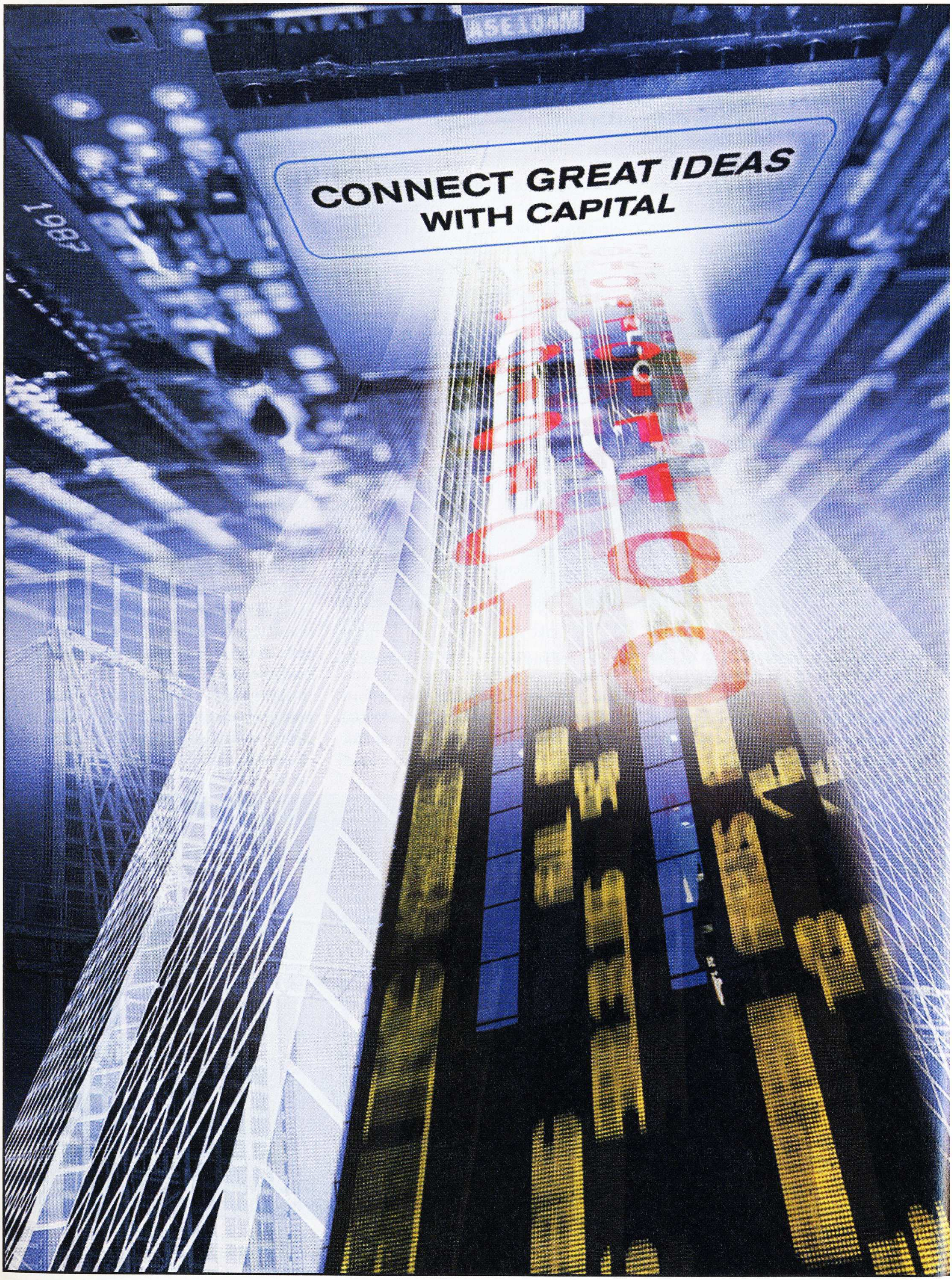
Such large efforts by major companies might just change the way we get from here to there, as well as how we power our houses. "[This technology] begins to obliterate the distinctions between stationary and mobile applications," says John Turner, a principal scientist at the National Renewable Energy Laboratory in Golden, CO.

Like many other disruptive technologies, this one starts with a simple vision: in this case, a fuel cell skateboard in every driveway. — *David Talbot*




COURTESY OF GM RESEARCH

**A General Motors prototype fuel cell receives hydrogen gas from pipes (lower right) and emits water vapor from tubing (top right). Inside, hydrogen protons and electrons are separated, creating a flow of electricity between two electrodes (top).**


CONNECT GREAT IDEAS
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# ADVANCED BRAIN IMAGING

group **Hitachi Advanced Research Labs' brain science applications program**
goal **Improving education through brain imaging**

The search for a better brain-imaging technology has taken a novel turn at Hitachi Advanced Research Labs in Hatoyama, Japan. The company's researchers aren't just perfecting a new imaging machine—a reasonable goal for the electronics giant—they are helping to conduct basic brain-science studies geared at improving education and even promoting world peace. To achieve those goals, researchers are using imaging advances to do everything from observing the pathways of comprehension in newborns to tracking the ways an adult brain compensates for injuries while it performs such high-level tasks as writing, solving math problems, and responding to spoken commands.

Hitachi's technology, known as optical topography, is well suited for such studies. Unlike other brain-imaging methods, optical topography allows the patient to sit, move, write, and talk while it monitors activity in specific regions of the subject's cerebral cortex, the outer layer of the brain where such functions as language are handled. The patient simply wears headgear festooned with optical probes and detectors, and the imaging system uses near-infrared light to provide a view of blood flow. Changes in blood flow might indicate comprehension: for example, flow to the language areas of the cerebral cortex increases when the patient recognizes spoken words. Optical topography detects such changes because although near-infrared light passes through skin and skull, it is absorbed in the cerebral cortex by hemoglobin in the blood. The more blood flow, the more hemoglobin—and the less light is reflected back to the device's detectors.

Other companies are also developing medical imaging equipment, but it is the application of this technology to basic cognitive studies that makes the Hitachi research group stand out. One long-term goal, for instance, is to use insights gleaned from the imaging to improve educational curricula. "Education is becoming a natural-science field, and the key is observing brain activity by noninvasive means," says Hitachi senior chief scientist Hideaki Koizumi, inventor of the technology. "We can improve educational efficiency by knowing the exact developmental stages of a child." Information from the imaging could also aid the development of better therapies for elderly patients who suffer from dementia or for victims of strokes and other brain injuries.

Optical probes and detectors send infrared light into the head of Hideaki Koizumi. The brain-imaging system detects blood flow in his cerebral cortex, providing information on high-level functions such as writing, solving math problems, and language comprehension.

Koizumi also serves as director of brain science and education research at the Japanese Ministry of Education, Culture, Sports, Science, and Technology. In this capacity, he is developing a 10-year plan for Japan's brain science research, a road map he expects to complete in March. His goals are ambitious: "I am very much interested in how to cultivate warm heart and generosity that must lead to world peace," he says. It's possible to think on these grand terms, he adds, because observing brain functions can lead to insights into what triggers human behavior.

To get started, 10 researchers from the Hitachi lab are collaborating with cognitive scientists at universities in Japan and abroad. In a study conducted at the Laboratory of Cognitive and Psycholinguistic Sciences in Paris, researchers wired probes to newborn babies and watched the language centers of the babies' brains. The images showed blood flow increasing when the babies heard their mothers' native language and decreasing when they heard foreign languages. Another Hitachi collaboration is under way at Tohoku University in Sendai, Japan, where researchers are using the device to learn how children's brains compensate for injuries suffered at birth.

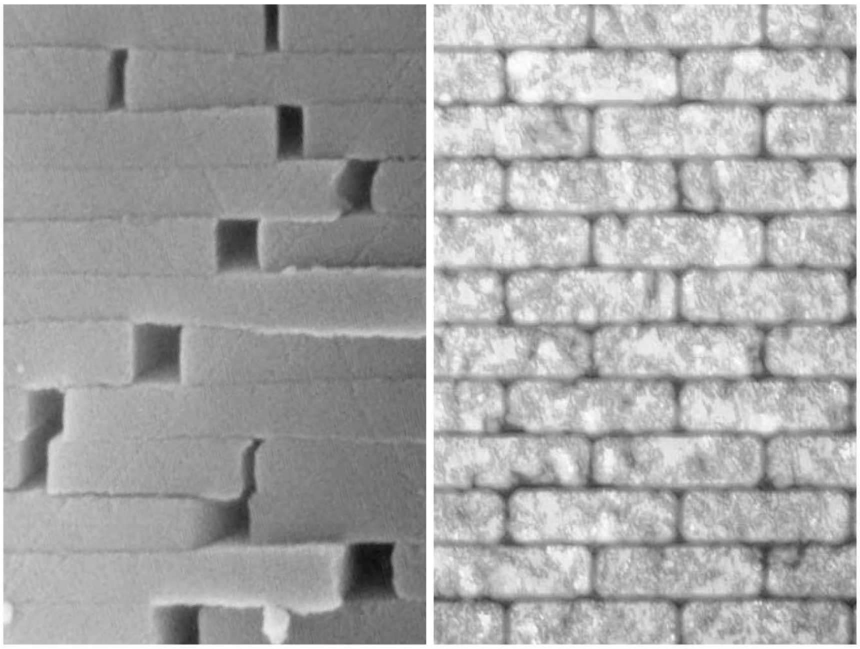
While Hitachi sees a potentially large market for the brain-imaging technology, its grander motivations have drawn praise from pioneering biophysicist Britton Chance, who developed a related version of the optical-imaging system in 1996. "It's a humanitarian effort," says Chance, a professor emeritus at University of Pennsylvania. "This is a quirk of corporate interest, a very unusual event."

Indeed, if optical-topography research begins to help improve education, the Hitachi program will have had a tremendous impact even if it falls short of bringing about world peace. — *David Talbot*

TOM WAGNER/CORBIS/SABA

# NANO CERAMICS

group **General Electric's nanotechnology program**
goal **Tougher ceramics based on the microstructure of seashells**



**Researchers at General Electric are studying just why seashells resist cracking and breaking. The microstructure of mother-of-pearl found in red abalone shows layers of platelets (left). On the right is GE's latest version of a synthetic ceramic inspired by seashells.**

COURTESY OF MEHMET SARIKAYA, UNIVERSITY OF WASHINGTON, SEATTLE (SHELL); COURTESY OF GE RESEARCH (CERAMIC)

Why does a ceramic coffee cup break much more easily than a seashell? That might seem like a question to ponder during a long, lazy afternoon at the beach. But General Electric, a company known in recent years for aiming its bottom line research at specific business issues, is looking for the answer and using a rather unusual strategy: it is reverse-engineering seashells. Researchers in the company's 25-person nanotechnology group want to understand what nature has done right, as well as how nature's approach might someday be used to build better ceramic materials for jet engines and power turbines.

Unlike typical GE research projects, the seashell effort has no specific product goals—and no time line. Indeed, say company insiders, this is exactly the type of project that just two years ago the company would have rejected as being far too speculative. But the 110-year-old corporation that gave the world better light bulbs is renewing its push to find disruptive technologies. And that has led to its work on seashells, along with many other similarly high-risk research projects that—if they ever pay off—could take up to 10 years to yield results. "This is a very new time line and level of risk for GE," says Margaret Blohm, who heads the nanotech group.

But even though the seashell research falls into the high-risk category, it is solidly grounded in the growing discipline of nanoscience. Seashells, it turns out, have some surprising qualities, and they have been attracting the attention of researchers for more than a decade. "They're extraordinarily tough," says Case Western Reserve University materials science professor Arthur Heuer, who attributes their crack- and shatter-resistant properties to "an exquisite microarchitecture." Understanding the details of this nanostructure, he adds, could lead to insights into how to make ceramics that are similarly tough and shatter resistant.

An abalone shell is made chiefly of calcium carbonate, which is organized into multisided "tablets" that are closely packed in layers. A rubbery polymer glues the tablets together and serves as a cushion between the layers. The shells are unlikely to break or shatter because when a microcrack does form, it propagates along complicated, tortuous paths that, in effect, diffuse the crack. The polymer layers also absorb the damage; so while shells get the equivalent of bumps and bruises, they don't easily break.

GE materials scientist Mohan Manoharan and his team started work on seashells in January 2002, when the company formed its nanotech group. Before the group started trying to synthesize materials based on seashell structure, however, the researchers spent months poring over academic articles, trying to understand why "the right atom is in the right place," says Manoharan. Their study of seashell microstructure complete, the researchers began attempts to replicate nature's results. Manoharan's team is building computer models of shell-inspired materials, starting with models that will consist of just a few layers. The group has also begun to synthesize the model materials.

The prospects are tantalizing for General Electric, a leading maker of high tech ceramics, including coatings that protect metal parts of jet engines against extremely high temperatures. The development of sufficiently strong and shatter-resistant lightweight ceramics could lead to all-ceramic components and, therefore, far lighter and more efficient jet engines.

For Manoharan, a former academic, the work on shells is just the type of basic research that comes naturally. When he was seven years old, he recalls, he broke his foot in a cricket accident at school in India. "I sat at home and wondered how bones healed," he says. And he asked himself why people couldn't build materials as sophisticated as those found in nature.

Now, years later in a lab at GE's research center, he is pondering shells, not bones. But his question remains much the same. — *Julie Claire Diop*

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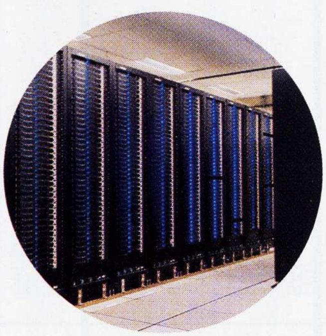
# Can a microscopic piece of technology solve enterprise-sized problems?

An Intel engineer holds a batch of silicon wafers, each one containing up to hundreds of processors and up to 12 billion transistors.

## You're probably familiar with the emblem on so many PCs: Intel Inside®. But 88% of the world's servers* are powered by Intel processors, too.



The data center powers today's enterprise. Intel technology makes powerful servers more cost-effective.

* Based on total server shipments 1996-CY Q1 2002 according to IDC's Worldwide Quarterly Server Tracker, May 2002.

# THE CORPORATE R&D SCORECARD 2002

*Technology Review*'s 2002 Corporate R&D Scorecard reports the annual research and development spending of the world's top 150 technology companies. Each company has been assigned to one of 12 sectors on the basis of its primary business. The scorecard figures are derived from annual reports and U.S. Securities and Exchange Commission filings for fiscal years ending between June 1, 2001 and May 31, 2002. Depending on when each company's fiscal year ends, its most recent filings could be designated either fiscal year 2001 or fiscal year 2002. To avoid confusion, therefore, we chose to categorize our figures as being from the companies' "Latest Year." A more extensive listing of 300 top companies is available on the Web at http://www.technologyreview.com/rdscorecard2002.

| | | R&D SPENDING (IN MILLIONS OF DOLLARS) | | | REVENUE (IN MILLIONS OF DOLLARS) | | R&D SPENDING AS % OF REVENUE | | NUMBER OF EMPLOYEES | R&D SPENDING PER EMPLOYEE (IN DOLLARS) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | COMPANY | LATEST YEAR* | RANK | % CHANGE FROM PREVIOUS YEAR†† | LATEST YEAR* | % CHANGE FROM PREVIOUS YEAR | LATEST YEAR* | RANK | LATEST YEAR* | LATEST YEAR* | RANK |
| AEROSPACE | **BAE Systems** (U.K.) | 2,516 | 1 | 10.4 | 13,019 | -11.0 | 19.3 | 1 | 70,100 | 35,886 | 1 |
| | **Boeing** (U.S.) | 1,936 | 2 | -3.1 | 58,198 | 13.4 | 3.3 | 6 | 188,000 | 10,298 | 4 |
| | **EADS** (Netherlands) | 1,832 | 3 | — | 27,573 | 53.6 | 6.6 | 2 | 102,967 | 17,790 | 2 |
| | **United Technologies** (U.S.) | 1,254 | 4 | -3.7 | 27,897 | 4.9 | 4.5 | 4 | 152,000 | 8,250 | 5 |
| | **Honeywell International** (U.S.) | 832 | 5 | 1.7 | 23,652 | -5.5 | 3.5 | 5 | 115,000 | 7,235 | 6 |
| | **Rolls-Royce** (U.K.) | 516 | 6 | -8.4 | 9,112 | 2.5 | 5.7 | 3 | 43,300 | 11,905 | 3 |
| | **Raytheon** (U.S.) | 475 | 7 | -9.7 | 16,867 | -0.2 | 2.8 | 7 | 87,200 | 5,447 | 7 |
| AUTOMOTIVE | **Ford Motor** (U.S.) | 7,400 | 1 | 8.8 | 162,412 | -4.5 | 4.6 | 8 | 354,431 | 20,879 | 3 |
| | **General Motors** (U.S.) | 6,200 | 2 | -6.1 | 177,260 | -4.0 | 3.5 | 13 | 365,000 | 16,986 | 7 |
| | **DaimlerChrysler** (Germany) | 5,312 | 3 | -9.3 | 136,864 | -8.8 | 3.9 | 11 | 379,544 | 13,995 | 10 |
| | **Toyota Motor** (Japan) | 4,745 | 4 | 9.1 | 120,972 | -0.5 | 3.9 | 11 | 246,702 | 19,234 | 4 |
| | **Honda Motor** (Japan) | 3,165 | 5 | -1.0 | 58,959 | 0.7 | 5.4 | 6 | 120,600 | 26,240 | 2 |
| | **Nissan Motor** (Japan) | 2,099 | 6 | 0.0 | 49,620 | -10.1 | 4.2 | 10 | 118,161 | 17,765 | 5 |
| | **Bosch**† (Germany) | 1,876 | 7 | -8.4 | 29,156 | -2.0 | 6.4 | 4 | 198,666 | 9,443 | 12 |
| | **Renault** (France) | 1,732 | 8 | -8.5 | 32,544 | -12.3 | 5.3 | 7 | 159,608 | 10,854 | 11 |
| | **Delphi Automotive Systems** (U.S.) | 1,700 | 9 | -2.9 | 26,088 | -10.5 | 6.5 | 3 | 195,000 | 8,718 | 13 |
| | **Peugeot** (France) | 1,552 | 10 | 3.3 | 46,443 | 13.8 | 3.3 | 14 | — | — | — |
| | **BMW** (Germany) | 1,489 | 11 | — | 34,435 | 5.4 | 4.3 | 9 | 97,275 | 15,306 | 8 |
| | **Denso** (Japan) | 1,487 | 12 | -7.3 | 19,228 | 5.3 | 7.7 | 1 | 86,639 | 17,158 | 6 |
| | **Adam Opel**† (Germany) | 1,193 | 13 | — | 15,819 | -9.4 | 7.5 | 2 | 40,298 | 29,612 | 1 |
| | **Visteon** (U.S.) | 1,119 | 14 | -6.6 | 17,843 | -8.3 | 6.3 | 5 | 79,000 | 14,165 | 9 |
| BIOTECH | **Amgen** (U.S.) | 865 | 1 | -1.2 | 4,016 | 10.6 | 21.5 | 8 | 7,700 | 112,338 | 5 |
| | **Genentech** (U.S.) | 517 | 2 | 11.3 | 2,082 | 26.5 | 24.8 | 6 | 4,950 | 104,403 | 6 |
| | **Millennium Pharmaceuticals** (U.S.) | 401 | 3 | 49.1 | 246 | 25.4 | 162.7 | 1 | 1,900 | 210,829 | 2 |
| | **Genzyme** (U.S.) | 360 | 4 | -5.4 | 1,224 | 35.5 | 29.4 | 5 | 5,200 | 69,148 | 8 |
| | **Chiron** (U.S.) | 344 | 5 | 17.6 | 1,056 | 19.0 | 32.6 | 3 | 3,736 | 92,188 | 7 |
| | **Applera** (U.S.) | 323 | 6 | 17.7 | 1,644 | 19.9 | 19.7 | 10 | 5,544 | 58,336 | 10 |
| | **Biogen** (U.S.) | 315 | 7 | 3.9 | 1,043 | 12.6 | 30.1 | 4 | 1,992 | 157,910 | 3 |
| | **Serono** (Switzerland) | 309 | 8 | 17.3 | 1,249 | 8.9 | 24.7 | 7 | 4,501 | 68,589 | 9 |
| | **Incyte Genomics** (U.S.) | 213 | 9 | 10.8 | 219 | 12.9 | 97.3 | 2 | 585 | 364,677 | 1 |
| | **Immunex**† (U.S.) | 205 | 10 | 22.8 | 987 | 14.5 | 20.7 | 9 | 1,303 | 157,060 | 4 |
| CHEMICALS | **Bayer** (Germany) | 2,227 | 1 | 1.2 | 25,908 | -6.5 | 8.6 | 3 | 116,900 | 19,054 | 5 |
| | **DuPont** (U.S.) | 1,588 | 2 | -10.0 | 24,726 | -12.5 | 6.4 | 6 | 79,000 | 20,101 | 4 |
| | **Dow Chemical** (U.S.) | 1,141 | 3 | 27.1 | 27,805 | -5.9 | 4.1 | 9 | 52,689 | 21,655 | 3 |
| | **BASF** (Germany) | 1,117 | 4 | -20.8 | 29,096 | -12.4 | 3.8 | 10 | 92,545 | 12,064 | 8 |
| | **Akzo Nobel** (Netherlands) | 758 | 5 | 3.9 | 12,632 | -2.4 | 6.0 | 7 | 66,300 | 11,437 | 9 |
| | **Syngenta** (Switzerland) | 723 | 6 | 34.6 | 6,323 | 29.7 | 11.4 | 1 | — | — | — |
| | **Mitsubishi Chemical** (Japan) | 677 | 7 | 9.9 | 14,257 | -9.9 | 4.8 | 8 | 38,617 | 17,541 | 6 |
| | **Monsanto** (U.S.) | 560 | 8 | -4.8 | 5,462 | -0.6 | 10.3 | 2 | 14,600 | 38,356 | 1 |
| | **Sumitomo Chemical** (Japan) | 534 | 9 | -0.3 | 8,155 | -13.5 | 6.5 | 5 | 17,016 | 31,376 | 2 |
| | **Merck** (Germany) | 517 | 10 | 2.5 | 6,740 | 8.2 | 7.7 | 4 | 34,294 | 15,071 | 7 |
| COMPUTERS (HARDWARE) | **IBM** (U.S.) | 5,290 | 1 | 21.7 | 85,866 | -2.9 | 6.2 | 8 | 319,876 | 16,538 | 8 |
| | **Fujitsu** (Japan) | 2,802 | 2 | -23.3 | 40,096 | -19.3 | 7.0 | 6 | 170,111 | 16,470 | 9 |
| | **NEC** (Japan) | 2,672 | 3 | -14.5 | 40,849 | -16.6 | 6.5 | 7 | 141,909 | 18,827 | 7 |
| | **Hewlett-Packard** (U.S.) | 2,670 | 4 | 0.9 | 45,226 | -7.5 | 5.9 | 10 | 86,200 | 30,974 | 5 |
| | **Toshiba** (Japan) | 2,612 | 5 | -12.1 | 43,196 | -19.9 | 6.0 | 9 | 176,398 | 14,807 | 10 |
| | **Sun Microsystems** (U.S.) | 2,093 | 6 | 27.5 | 18,250 | 16.1 | 11.5 | 3 | 43,700 | 47,895 | 2 |
| | **Canon** (Japan) | 1,800 | 7 | -0.3 | 23,946 | -7.2 | 7.5 | 5 | 93,620 | 19,231 | 6 |
| | **Mitsubishi Electric** (Japan) | 1,638 | 8 | -7.9 | 29,221 | -21.9 | 5.6 | 12 | 116,192 | 14,101 | 11 |
| | **Xerox** (U.S.) | 997 | 9 | -6.9 | 17,008 | -9.3 | 5.9 | 10 | 78,900 | 12,636 | 12 |
| | **EMC** (U.S.) | 929 | 10 | 18.6 | 7,091 | -20.1 | 13.1 | 2 | 20,100 | 46,204 | 3 |
| | **Ricoh** (Japan) | 647 | 11 | -8.7 | 13,392 | -3.9 | 4.8 | 13 | 74,209 | 8,719 | 13 |
| | **Maxtor** (U.S.) | 531 | 12 | 126.0 | 3,797 | 40.4 | 14.0 | 1 | 9,811 | 54,134 | 1 |
| | **Apple Computer** (U.S.) | 441 | 13 | 16.1 | 5,363 | -32.8 | 8.2 | 4 | 11,434 | 38,569 | 4 |
| COMPUTERS (SOFTWARE) | **Microsoft** (U.S.) | 4,379 | 1 | 16.0 | 25,296 | 10.2 | 17.3 | 7 | 47,600 | 91,996 | 2 |
| | **Oracle** (U.S.) | 1,076 | 2 | -5.5 | 9,673 | -11.8 | 11.1 | 10 | 42,927 | 25,069 | 10 |
| | **SAP** (Germany) | 804 | 3 | -10.2 | 6,572 | 13.5 | 12.2 | 9 | 28,410 | 28,306 | 9 |
| | **Computer Associates International** (U.S.) | 678 | 4 | -2.4 | 2,964 | -29.3 | 22.9 | 3 | 16,600 | 40,843 | 6 |
| | **Avaya** (U.S.) | 568 | 5 | 21.4 | 6,793 | -12.1 | 8.4 | 11 | 23,000 | 24,696 | 11 |
| | **Automatic Data Processing** (U.S.) | 514 | 6 | 11.7 | 9,464 | 11.5 | 5.4 | 12 | 41,000 | 12,543 | 12 |
| | **BMC Software** (U.S.) | 479 | 7 | 104.2 | 1,286 | -14.5 | 37.3 | 1 | 6,335 | 75,643 | 3 |
| | **Electronic Arts** (U.S.) | 388 | 8 | -1.0 | 1,725 | 30.4 | 22.5 | 4 | 3,500 | 110,782 | 1 |
| | **Cadence Design Systems** (U.S.) | 322 | 9 | 21.7 | 1,430 | 11.8 | 22.5 | 4 | 5,600 | 57,478 | 5 |
| | **PeopleSoft** (U.S.) | 304 | 10 | -5.2 | 2,073 | 19.4 | 14.7 | 8 | 8,436 | 36,024 | 7 |
| | **I2 Technologies** (U.S.) | 303 | 11 | -5.4 | 986 | -12.5 | 30.8 | 2 | 4,800 | 63,150 | 4 |
| | **3Com** (U.S.) | 286 | 12 | -46.7 | 1,478 | -47.6 | 19.3 | 6 | 8,165 | 34,977 | 8 |
| GS/MEDICAL | **Bristol-Myers Squibb** (U.S.) | 5,003 | 1 | 158.0 | 19,423 | 6.6 | 25.8 | 1 | 46,000 | 108,761 | 1 |
| | **Pfizer** (U.S.) | 4,847 | 2 | 9.3 | 32,084 | 8.5 | 15.1 | 9 | 90,000 | 53,856 | 5 |
| | **GlaxoSmithKline** (U.K.) | 3,817 | 3 | -0.3 | 29,503 | 7.6 | 12.9 | 16 | 107,899 | 35,378 | 14 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Johnson and Johnson** (U.S.) | 3,696 | 4 | 24.0 | 33,004 | 10.6 | 11.2 | 17 | 101,800 | 36,306 | 10 |
| | **Aventis** (France) | 3,116 | 5 | -3.0 | 20,539 | -0.3 | 15.2 | 8 | 91,729 | 33,975 | 16 |
| | **Abbott Laboratories** (U.S.) | 2,908 | 6 | 115.2 | 16,285 | 18.5 | 17.9 | 3 | 71,426 | 40,713 | 8 |
| | **AstraZeneca** (U.K.) | 2,773 | 7 | -4.1 | 16,480 | -9.0 | 16.8 | 5 | 52,600 | 52,719 | 6 |
| | **Novartis** (Switzerland) | 2,483 | 8 | -10.0 | 18,993 | -10.5 | 13.1 | 15 | 71,116 | 34,920 | 15 |
| | **Merck** (U.S.) | 2,456 | 9 | 4.8 | 47,716 | 18.2 | 5.1 | 20 | 78,100 | 31,452 | 17 |
| | **Eli Lilly** (U.S.) | 2,426 | 10 | 20.2 | 11,543 | 6.3 | 21.0 | 2 | 41,100 | 59,017 | 2 |
| | **Roche** (Switzerland) | 2,308 | 11 | -1.4 | 17,289 | 1.7 | 13.3 | 13 | 63,717 | 36,221 | 11 |
| | **Pharmacia** (U.S.) | 2,263 | 12 | -17.8 | 13,837 | 9.4 | 16.4 | 6 | 59,600 | 37,970 | 9 |
| | **Wyeth** (U.S.) | 1,870 | 13 | 10.8 | 14,129 | 6.9 | 13.2 | 14 | 52,289 | 35,757 | 13 |
| | **Schering-Plough** (U.S.) | 1,312 | 14 | -1.6 | 9,802 | -0.1 | 13.4 | 12 | 29,800 | 44,027 | 7 |
| | **Medtronic** (U.S.) | 939 | 15 | 62.6 | 6,411 | 15.5 | 14.7 | 11 | 26,050 | 36,058 | 12 |
| | **Sanofi-Synthelabo** (France) | 923 | 16 | 5.7 | 5,809 | 5.4 | 15.9 | 7 | 30,514 | 30,250 | 19 |
| | **Takeda Chemical** (Japan) | 803 | 17 | -1.3 | 8,049 | -7.8 | 10.0 | 18 | 14,511 | 55,340 | 4 |
| | **Schering** (Germany) | 774 | 18 | 3.2 | 4,335 | 4.4 | 17.8 | 4 | 25,056 | 30,872 | 18 |
| | **Baxter International** (U.S.) | 677 | 19 | 7.6 | 7,663 | 11.1 | 8.8 | 19 | 48,000 | 14,104 | 20 |
| | **Sankyo** (Japan) | 654 | 20 | -8.4 | 4,396 | -11.0 | 14.9 | 10 | 11,244 | 58,123 | 3 |
| ELECTRICAL/ELECTRONICS | **Siemens** (Germany) | 6,028 | 1 | 11.6 | 77,329 | 2.1 | 7.8 | 7 | 484,000 | 12,455 | 10 |
| | **Matsushita Electric** (Japan) | 4,529 | 2 | -8.1 | 55,069 | -20.9 | 8.2 | 6 | 267,196 | 16,949 | 7 |
| | **Motorola** (U.S.) | 4,358 | 3 | -8.6 | 30,004 | -20.2 | 14.5 | 3 | 111,000 | 39,261 | 3 |
| | **Sony** (Japan) | 3,469 | 4 | -8.1 | 60,687 | -8.4 | 5.7 | 10 | 168,000 | 20,650 | 6 |
| | **Hitachi** (Japan) | 3,327 | 5 | -15.7 | 64,015 | -16.0 | 5.2 | 11 | 306,989 | 10,837 | 11 |
| | **Philips Electronics** (Netherlands) | 2,965 | 6 | 16.0 | 28,952 | -17.2 | 10.2 | 5 | 188,643 | 15,718 | 8 |
| | **Agilent Technologies** (U.S.) | 1,349 | 7 | 7.2 | 8,396 | -10.3 | 16.1 | 1 | 41,000 | 32,902 | 4 |
| | **Sharp** (Japan) | 1,009 | 8 | -16.2 | 14,445 | -20.8 | 7.0 | 9 | 46,518 | 21,681 | 5 |
| | **Sanyo Electric** (Japan) | 857 | 9 | -13.1 | 16,914 | -16.7 | 5.1 | 12 | 80,500 | 10,649 | 12 |
| | **Emerson Electric** (U.S.) | 594 | 10 | 0.0 | 15,480 | -0.4 | 3.8 | 14 | 124,500 | 4,770 | 16 |
| | **Matsushita Electric Works** (Japan) | 466 | 11 | -9.3 | 9,985 | -9.6 | 4.7 | 13 | 46,041 | 10,112 | 13 |
| | **Tokyo Electron** (Japan) | 431 | 12 | -10.1 | 3,346 | -49.0 | 12.9 | 4 | 10,171 | 42,380 | 2 |
| | **Qualcomm** (U.S.) | 415 | 13 | 3.6 | 2,680 | -16.2 | 15.5 | 2 | 6,500 | 63,809 | 1 |
| | **Sumitomo Electric** (Japan) | 388 | 14 | -4.4 | 11,892 | -11.2 | 3.3 | 17 | 69,959 | 5,545 | 14 |
| | **Invensys** (U.K.) | 379 | 15 | -9.3 | 9,984 | -14.2 | 3.8 | 14 | 83,680 | 4,535 | 17 |
| | **Omron** (Japan) | 332 | 16 | -13.9 | 4,276 | -20.6 | 7.8 | 7 | 25,124 | 13,198 | 9 |
| | **Thomson Multimedia** (France) | 329 | 17 | 1.6 | 9,395 | 11.8 | 3.5 | 16 | 62,862 | 5,241 | 15 |
| HIGH TECH CONGLOMERATES | **General Electric** (U.S.) | 1,980 | 1 | 6.1 | 125,679 | -2.2 | 1.6 | 6 | 310,000 | 6,387 | 4 |
| | **Fuji Photo Film** (Japan) | 1,176 | 2 | 64.1 | 19,229 | 53.4 | 6.1 | 2 | 72,569 | 16,209 | 1 |
| | **3M** (U.S.) | 1,084 | 3 | -1.5 | 16,079 | -3.9 | 6.7 | 1 | 71,669 | 15,125 | 2 |
| | **Eastman Kodak** (U.S.) | 779 | 4 | -0.6 | 13,234 | -5.4 | 5.9 | 3 | 75,100 | 10,373 | 3 |
| | **ABB** (Switzerland) | 654 | 5 | -7.0 | 23,726 | 3.3 | 2.8 | 4 | 156,865 | 4,169 | 6 |
| | **Tyco International** (Bermuda) | 572 | 6 | 8.4 | 36,048 | 24.6 | 1.6 | 6 | 242,500 | 2,359 | 7 |
| | **TRW** (U.S.) | 442 | 7 | -50.3 | 16,383 | -4.9 | 2.7 | 5 | 93,700 | 4,717 | 5 |
| PETROLEUM | **Schlumberger** (Netherlands Antilles) | 704 | 1 | 30.3 | 13,746 | 43.0 | 5.1 | 1 | 81,000 | 8,696 | 1 |
| | **ExxonMobil** (U.S.) | 603 | 2 | 6.9 | 187,510 | -9.0 | 0.3 | 3 | 97,900 | 6,159 | 2 |
| | **Elf Aquitaine**† (France) | 462 | 3 | -33.0 | 105,845 | 179.2 | 0.4 | 2 | 123,203 | 3,750 | 4 |
| | **Royal Dutch/Shell** (Netherlands) | 387 | 4 | -0.5 | 135,211 | -9.3 | 0.3 | 3 | 91,000 | 4,253 | 3 |
| | **BP** (U.K.) | 385 | 5 | -11.3 | 174,218 | 17.7 | 0.2 | 5 | 110,150 | 3,495 | 5 |
| SEMICONDUCTORS | **Intel** (U.S.) | 3,994 | 1 | -0.3 | 26,539 | -21.3 | 15.1 | 16 | 83,400 | 47,890 | 9 |
| | **Texas Instruments** (U.S.) | 1,598 | 2 | -8.5 | 8,201 | -30.9 | 19.5 | 9 | 34,724 | 46,020 | 10 |
| | **Applied Materials** (U.S.) | 1,209 | 3 | 9.1 | 7,343 | -23.2 | 16.5 | 14 | 17,365 | 69,611 | 4 |
| | **Infineon Technologies** (Germany) | 1,057 | 4 | 6.7 | 5,040 | -28.4 | 21.0 | 6 | 33,813 | 31,254 | 15 |
| | **STMicroelectronics** (Switzerland) | 978 | 5 | -4.7 | 6,304 | -18.8 | 15.5 | 15 | 40,000 | 24,448 | 17 |
| | **LSI Logic** (U.S.) | 678 | 6 | 39.6 | 1,785 | -34.8 | 38.0 | 2 | 6,737 | 100,595 | 1 |
| | **Advanced Micro Devices** (U.S.) | 651 | 7 | 1.4 | 3,892 | -16.2 | 16.7 | 13 | 14,415 | 45,156 | 11 |
| | **Micron Technology** (U.S.) | 490 | 8 | 14.5 | 3,936 | -38.1 | 12.4 | 17 | 18,100 | 27,044 | 16 |
| | **Conexant Systems** (U.S.) | 483 | 9 | -23.4 | 1,063 | -49.5 | 45.5 | 1 | 6,900 | 69,999 | 3 |
| | **Analog Devices** (U.S.) | 474 | 10 | 18.4 | 2,277 | -11.7 | 20.8 | 7 | 9,000 | 52,687 | 7 |
| | **National Semiconductor** (U.S.) | 441 | 11 | -3.3 | 1,495 | -29.2 | 29.5 | 4 | 10,300 | 42,816 | 13 |
| | **ASML** (Netherlands) | 365 | 12 | 82.1 | 1,651 | -18.2 | 22.1 | 5 | 7,070 | 51,694 | 8 |
| | **KLA-Tencor** (U.S.) | 356 | 13 | 44.8 | 2,104 | 40.4 | 16.9 | 12 | 6,400 | 55,699 | 6 |
| | **Maxim Integrated Products** (U.S.) | 280 | 14 | 97.0 | 1,577 | 14.6 | 17.8 | 11 | 6,317 | 44,361 | 12 |
| | **Novellus Systems** (U.S.) | 272 | 15 | 52.6 | 1,339 | 1.5 | 20.3 | 8 | 3,311 | 82,160 | 2 |
| | **Atmel** (U.S.) | 268 | 16 | 6.4 | 1,472 | -26.9 | 18.2 | 10 | 8,190 | 32,730 | 14 |
| | **Cypress Semiconductor** (U.S.) | 268 | 17 | 45.0 | 819 | -36.4 | 32.7 | 3 | 4,160 | 64,308 | 5 |
| TELECOMMUNICATIONS | **Cisco Systems** (U.S.) | 4,777 | 1 | 17.2 | 22,293 | 17.8 | 21.4 | 4 | 38,000 | 125,711 | 2 |
| | **Ericsson** (Sweden) | 4,516 | 2 | -1.6 | 22,447 | -25.0 | 20.1 | 5 | 85,200 | 53,002 | 7 |
| | **Lucent Technologies** (U.S.) | 3,520 | 3 | -29.9 | 21,294 | -26.3 | 16.5 | 9 | 77,000 | 45,714 | 9 |
| | **Nortel Networks** (Canada) | 3,380 | 4 | -35.0 | 18,033 | -41.1 | 18.7 | 8 | 53,600 | 63,061 | 5 |
| | **Nippon Telegraph and Telephone** (Japan) | 3,130 | 5 | -14.9 | 93,547 | -9.5 | 3.3 | 14 | 213,062 | 14,692 | 14 |
| | **Nokia** (Finland) | 2,672 | 6 | 11.9 | 27,925 | -0.5 | 9.6 | 13 | 53,849 | 49,628 | 8 |
| | **Alcatel** (France) | 2,567 | 7 | -1.8 | 22,698 | -21.8 | 11.3 | 11 | 99,314 | 25,845 | 11 |
| | **Matsushita Communication** (Japan) | 1,207 | 8 | -2.8 | 6,277 | -34.6 | 19.2 | 7 | 16,685 | 72,329 | 3 |
| | **Agere Systems** (U.S.) | 951 | 9 | -25.3 | 4,080 | -13.3 | 23.3 | 2 | 14,400 | 66,042 | 4 |
| | **Marconi** (U.K.) | 899 | 10 | — | 6,172 | -37.3 | 14.6 | 10 | 45,000 | 19,984 | 12 |
| | **Broadcom** (U.S.) | 878 | 11 | -16.3 | 962 | -12.3 | 91.3 | 1 | 2,728 | 321,822 | 1 |
| | **JDS Uniphase** (U.S.) | 719 | 12 | 51.7 | 3,233 | 126.0 | 22.2 | 3 | 19,948 | 36,049 | 10 |
| | **Corning** (U.S.) | 631 | 13 | -34.0 | 6,272 | -12.0 | 10.1 | 12 | 31,700 | 19,905 | 13 |
| | **British Telecommunications** (U.K.) | 518 | 14 | -3.7 | 29,441 | -2.6 | 1.8 | 16 | 108,600 | 4,773 | 15 |
| | **Alstom** (France) | 509 | 15 | -10.9 | 20,732 | -7.0 | 2.5 | 15 | 118,995 | 4,275 | 16 |
| | **France Telecom** (France) | 508 | 16 | 22.4 | 38,520 | 23.8 | 1.3 | 17 | 206,184 | 2,462 | 18 |
| | **Tellabs** (U.S.) | 425 | 17 | 2.5 | 2,200 | -35.1 | 19.3 | 6 | 7,334 | 58,012 | 6 |
| | **AT&T** (U.S.) | 325 | 18 | -19.2 | 52,550 | -5.4 | 0.6 | 18 | 117,800 | 2,759 | 17 |

*Data are for fiscal years ending between June 1, 2001 and May 31, 2002.

†Latest fiscal-year figures were unavailable for this company; figures are from previous year.

‡Immunex was acquired by Amgen, effective July 15, 2002.

††Figures may be affected by acquisitions and divestitures and may also reflect changes in R&D Scorecard reporting methodologies.

SOURCE: STANDARD & POOR'S

**Noisemaker:** James Collins builds devices that use noise to aid people who suffer from balance problems.

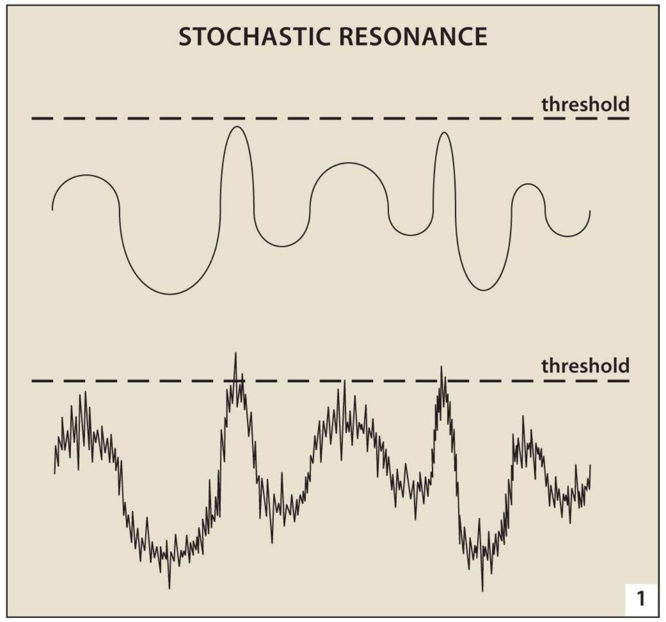
DEMO

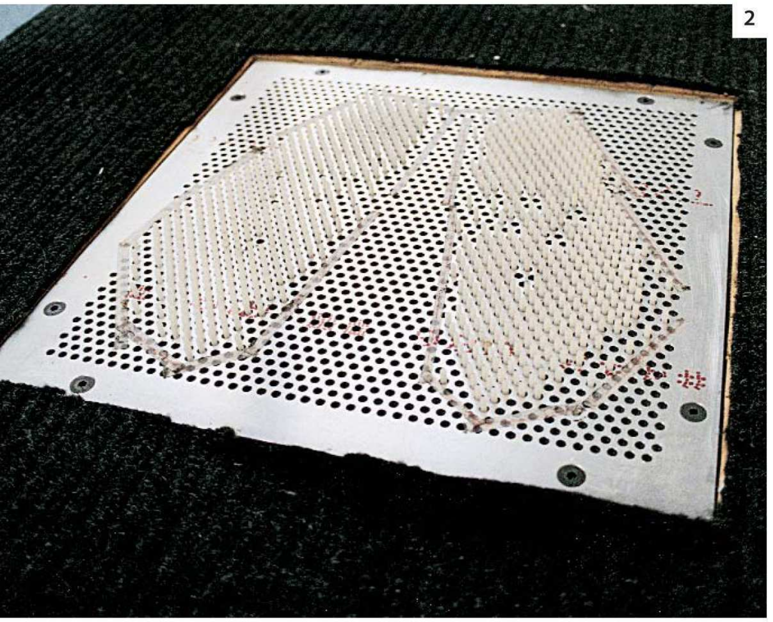
# BALANCE THERAPY

When we get old or sick, our sense of touch—and our balance—can suffer. James Collins thinks a little noise might help.

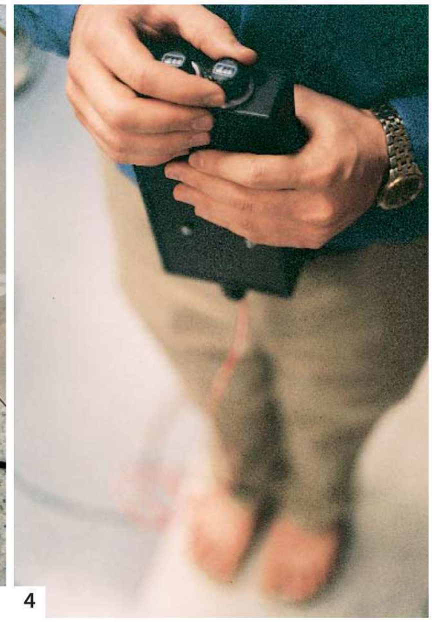
PHOTOGRAPHS BY JOHN SOARES

**Noise has a bad reputation, says Boston University bioengineer James Collins.** "We typically view noise as being detrimental to signal detection and information transmission," he explains. But Collins believes noise could actually help elderly people, diabetics, and stroke patients whose sense of touch has been dulled by age, injury, or ailment. His work builds on a discovery made two decades ago by physicists who found that in certain circumstances, adding noise aids the detection of weak signals. Researchers dubbed this odd phenomenon, in which noise essentially pushes a weak signal above a detection threshold, "stochastic resonance." Eight years ago, Collins began investigating the effect of stochastic resonance on people. "I recognized that all sensory neurons in humans are threshold-based," he says, and "these thresholds get elevated as a result of disease, age, and injury." This reduced ability to sense the world can have profound consequences. For the elderly, for instance, numbness in the feet is often a factor in falling—the leading cause of injury-related death in people over 65. So Collins and his team began to investigate whether noise, delivered via mechanical vibration or electrical stimulation, could restore lost sensation. In October, Collins showed *Technology Review* senior editor Rebecca Zacks an early prototype of a system—in the form of a vibrating pair of gel insoles—that might help take noise-based therapy to the streets.










**1. COUNTERING INTUITION.** The general principle at work in his technology, Collins says, "is a counterintuitive one. We, both as engineers and as everyday individuals, think of noise as a nuisance. You tune the static out of your radio." But in many systems there's an intermediate level of noise that will render a subthreshold signal detectable. From a manila folder, Collins pulls a simple illustration that makes the point. On the top, a smooth wave represents a noiseless signal. Because it falls entirely beneath a detection threshold, the signal is imperceptible. On the bottom of the illustration is the noisy version of the wave. The overall shape is preserved, but some of the spikes created by the addition of noise and signal now extend above the threshold. In other words, at least a portion of the signal is now detectable.

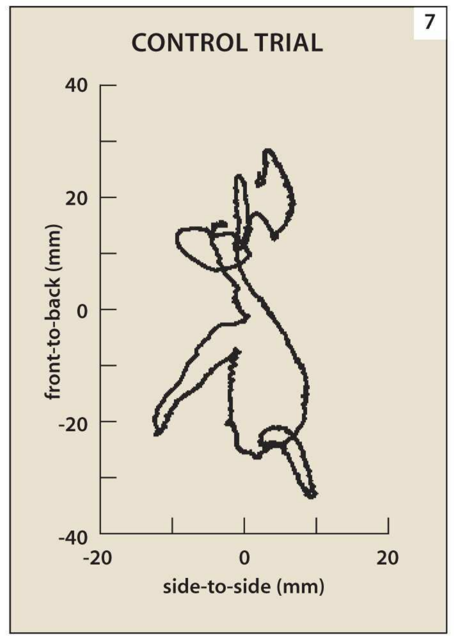
**2. TOE TICKLER.** Boosting the detection of tactile signals, Collins says, could make a profound difference for people whose sensitivity has been dulled by age or ailment. An elderly person, for example, might not be able to sense pressure against his or her foot. "This translates into difficulties with balance control and locomotion, which then translate into issues such as falls. One out of three individuals over the age of 65 falls each year, and a significant portion of those falls will result in serious injury," he says. To see whether introducing mechanical noise might improve balance control, Collins and graduate student Attila Priplata have built what Collins calls a vibrating shoebox. "It's an apparatus that has two motors underneath," he explains. "Connected to them are little plastic pylons that come up and that make contact with the subject's feet. They introduce random vibration on the soles of the subject's feet." In experiments with the device, both young and elderly volunteers swayed less when the pylons were vibrating—even though they couldn't tell when the device was turned on. "What we have found is that the noise that tends to be most effective is noise which is subsensory, so the subject does not actually detect feeling the noise," Collins says.

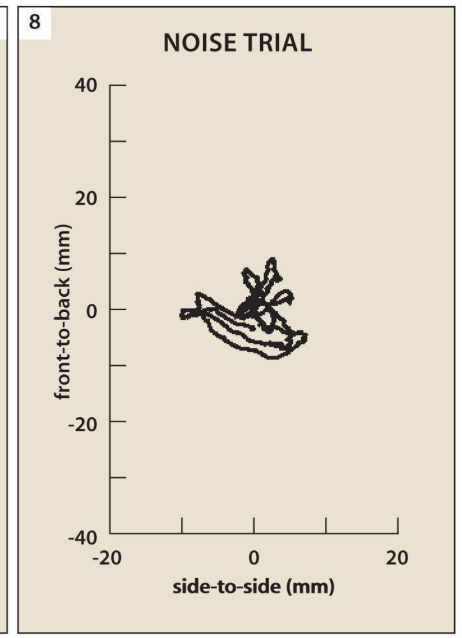
**3. DELUXE DR. SCHOLL'S.** These first studies, Collins says, showed that mechanical vibrations could help improve people's balance. But the device itself was unwieldy. "Obviously, you can't have 80-year-old Mrs. McGillicuddy walking around the mall with her vibrating shoeboxes," he says. "So Attila moved to designing a preprototype set of vibrating insoles." As Collins speaks, Priplata removes his shoes, arranges a pair of bulky translucent gel insoles on a platform on the lab floor, and steps onto them. "He's got actuators in there that can introduce mechanical vibration," Collins says, pointing to three quarter-size disks embedded in each insole. "It gets distributed somewhat by the gel."

**4. PERFECT FIT.** Priplata begins to calibrate the insoles using a handheld controller the size of a videotape. Starting with the vibration in the left insole turned up high, he slowly turns the left dial down, stopping just when he can no longer feel the movement. An assistant makes a note of that level, which represents Priplata's personal tactile threshold, while Priplata repeats the process with his right foot. Once the thresholds have been determined, he sets each insole at 90 percent of the threshold value to ensure that he won't be able to feel whether the noise is turned on or off. As Priplata fiddles with the controller, Collins describes his long-term vision: "This system would become self-contained in a shoe. The controller box would be reduced to a chip, and there would be some sort of battery that would be sufficiently powerful to drive the apparatus for a decent amount of time." Another question the researchers are interested in exploring, Collins says, "is how one could harness the energy that's generated during natural walking as a means to power the system."

**5-6. READY, STEADY.** With the insoles calibrated, Priplata puts himself through the same protocol the researchers use when they conduct their experiments with volunteers: he closes his eyes and stands as still as possible for 30 seconds at a time. For each of those intervals, a computer randomly decides to turn the insoles on or off; this way neither the subject nor the researcher knows when the noise is being introduced. A reflective sphere taped to Priplata's shoulder *(5)* allows his subtle movements to be tracked by two infrared cameras, arranged on nearby tripods *(6)*. "It turns out that none of us can stand completely still," Collins says. The muscles that hold us up "cannot produce constant force, so even in the finest of athletes there's always some fluctuation." What's more, Collins says, "Increased sway has been correlated with balance difficulties, and older individuals tend to sway more than young individuals."

**7-8. SWAY AWAY.** Priplata appears to be standing quite still. But when two 30-second intervals are over he walks to a computer and pulls up two graphs that reveal his movements, as recorded by the infrared cameras. The first, labeled "control trial," shows that with the insoles turned off, the marker on his shoulder moved several centimeters during the trial. The front-to-back movement is particularly pronounced, Collins says. With the insoles turned on—the "noise trial"—the marker's movements were confined to a one-centimeter radius. Looking over Priplata's shoulder at the graphs, Collins says that the results are fairly typical of what the researchers have been seeing in their experiments. "Perhaps most interesting in these studies is that with the noise, we can move the elderly close to the level of the young, in terms of quiet standing sway." Still, he says, "We have no idea if that will translate into reduced falling frequency." That's a question Collins hopes to answer in future experiments—once the insoles are refined enough to go for a walk. At the same time, he and others in the field are exploring a host of additional applications of noise. In his own lab, he says, "our goal is to actually have devices that can stimulate various parts of the body. We primarily have driven towards medical applications, but the technology works also for the healthy young. Looking out, one could imagine catsuits or bike shorts that would be used by athletes or individuals who are looking for just a slight edge from some enhanced sensory information." It might not be too long, he says, before many of us have our senses honed by noise. TR



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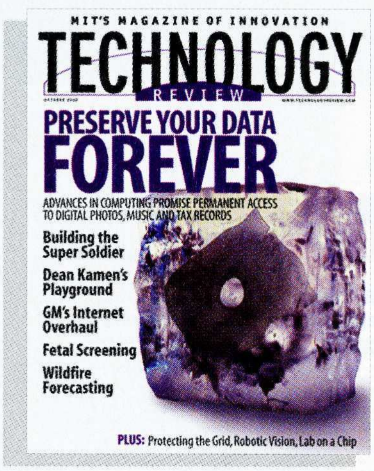


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FEATURE FOCUS 5

MOTOROLA'S SUPERCHIPS

The proceeds from this round will be used for product development and for the launch of the company's first product in 2003.

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Semiconductor Innovation LETTER

VOL. 1, NO. 1 12.02

INNOVATION, INVESTMENT AND OPPORTUNITY

## Fabless Firm eSilicon Gets $10M and Heads for Profitability

Sierra Logic, a fabless semiconductor company focused on providing very large-scale integration (VLSI) to the enterprise storage market, said it has raised $12 million in its second round of financing.

SEATTLE WA

New investor InterWest Partners led the round, while existing investors TPG Ventures, JPMorgan Partners, and QTV Capital also participated.

The proceeds from this round will be used for product development and for the launch of the company's first product in 2003.

Sierra Logic expects this funding to last into 2004 when it expects to reach profitability. CFO Rob Van Tuyle said the company began raising this round in June, seeking $12 million.

Tom Rosch, managing director and general partner at InterWest, has joined the company's board. Existing board members include Steve Foster, general partner at TPG Ventures; Randy Meals, vice president and managing director at QTV Capital; Vik Gupta, associate at JPMorgan Partners; and Bob Whitson, CEO of Sierra Logic.

Founded in 2001, Sierra Logic has raised $17.25 million to date. The company raised $5.25 million from QTV Capital, TPG Ventures, and individuals in its Series A.

The company has 26 employees and is hiring in engineering. —*Emily Westhafer*

## Intel, VCs Invest in Organic Semiconductor Firm Nanolayers

In an industry mostly dominated by silicon-based chips, a new firm claims to have found a way to commercialize the holy grail of the electronics industry-organic semiconductors.

4THPASS TECHNOLOGY, A DEVELOPER OF software to manage over-the-air transmissions to Java-enabled devices, said it has been acquired by Motorola.

4thpass executives said the deal enables Motorola to approach wireless carriers with an end-to-end J2ME product and enables 4thpass to continue its expansion into China and other countries outside its North American base.

SEATTLE WA

Founded in 1997, 4thpass Technology raised $8 million in its Series A round in May 2001 from (212) Ventures, Investcorp, Nextel Communications, OVP Venture Partners, and Motorola Ventures, which had a 5% stake in the company before the acquisition.

4thpass, including its staff and offices, will operate as a unit of Motorola's Personal Communications Sector. The company was co-founded by Mazin Ramadan, president and chief executive officer; Zeyad Ramadan, executive vice president; and Samir Mehta, chief technical officer. The co-founders have agreed to stay on for at least 12 to 18 months.

4thpass had been raising its Series B round for the last six months, targeting $20 million. The proceeds of the round were earmarked for expansion, including international markets, especially China. The company said it will continue with its expansion plans and will have a presence in Beijing. The company already has a foothold in the U.K., Spain, and Singapore, in addition to the U.S.

Motorola has three joint accounts with 4thpass, though none have been disclosed. Motorola will integrate 4thpass's Mobile Application System, which includes a set of Java servers, into its J2ME technology product portfolio. 4thpass has signed carrier deals with Telefonica Moviles, Nextel, and LG Telecom and reseller agreements with Ericsson and Siemens.

4thpass and Motorola entered into the deal two weeks ago and it is expected to close on September 20. —*Jeffrey Sanders*

## New Firm Raising Silicon-Focused Venture Capital Fund

**Applied Microtech, which develops industrial equipment for the semiconductor industry, said it** has raised EUR 1 million ($973,000) in its second round of funding.

New investor Siparex Ventures provided $500,000, while existing investors Emertec, Spromec, and Sudinnova contributed the remaining $473,000. The proceeds from this round will be used for the company's product launch, which is set for later this month. The company, which will most likely raise its third round in two years, plans to reach profitability at the end of 2003.

SEATTLE WA

In conjunction with the funding, undisclosed representatives from Emertec and Siparex Ventures have joined the company's board.

President Eric Pilat founded Applied Microtech in May 1999 to develop and market industrial equipment for the semiconductor industry based on a new interconnection process involving the microinjection of alloy in fusion using a new technology called Ball Grid Array (BGA).

The company's Tin-Up automated ball machine is designed to repair BGA, chip scale packaging, and connectors. The company's Tin-Up automated ball machine is designed to repair BGA, chip scale packaging, and connectors.

In 2000, Applied Microtech raised its first round of funding, totaling $473,000, from Emertec, Spromec, and Sudinnova. The company has 20 employees.

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## A DOSE OF COMMON SENSE

All over the world, fractious fights over ownership rights have raged unabated this past year, especially between rich and poor nations. This fall, we watched a classic face-off when China, finally acknowledging its enormous AIDS problem, broached the idea of making its own generic AIDS drugs. Depending on one's point of view, China's announcement was received as either a desperately overdue public-health decision or a frontal assault on the World Trade Organization and the U.S. pharmaceutical industry.

Many debates over intellectual property are driven by empty dogma. For reasons I've never quite fathomed, many supporters of intellectual-property rights hold the erroneous belief that more is always better: stronger ownership rights will always foster more innovation and a stronger economy. Conversely, plenty of people hold the equally dubious view that patent and copyright systems will always amass more power for elite companies, squash innovation, and exploit developing countries.

When one looks at catastrophes such as AIDS in China, it seems unquestionably clear that neither of these views make much sense. Strong intellectual-property protection will do nothing to put affordable medications into the hands of AIDS patients in China. Yet it is also undeniably true that we probably wouldn't have the drugs in the first place if it weren't for strong patent protection in the developed world.

Neither side seems able to get beyond the heavy rhetoric. But it turns out that there is a broad swath of common ground upon which to build a fruitful compromise. This, in essence, is the finding of a blue-ribbon commission appointed by the U.K. government. Commission members visited developing countries and recruited experts and activists worldwide to prepare 17 working papers addressing and considering a broad range of case studies and viewpoints. The commission's extraordinary report, issued this fall, is available at www.iprcommission.org.

The commission concluded that a global drive to expand patent protection in the pharmaceutical industry would mean higher-priced medicines for most developing countries and no significant benefit for their local industries. Perhaps even worse, the current system—based as it is on the economic incentives of vast, lucrative markets for patented drugs—would do little to stimulate research on diseases that affect primarily poor people, for example, schistosomiasis, caused by freshwater parasites.

The answer, the report says, is not for developing nations to abandon the nascent international intellectual-property system, as China essentially threatened to do in the case of AIDS drugs. Such a strategy is a prescription for increasing tensions that will likely lead to a spiral of retribution and create punitive trade barriers. Instead, the report argues, countries should individually mold patent and copyright regimes to fit their own needs. For instance, each country could spell out exceptions—such as compulsory licensing for drugs under specific circumstances—that would allow it to make and distribute cheap generic drugs but still uphold the basic patent framework.

Developing countries, the report adds, would be wise to institute explicit rules that exclude diagnostic, therapeutic, and surgical methods from patentability. Many developed nations have already done so, allowing for less expensive and wider dissemination of new and potentially life-saving techniques. The same strategies should be applied to agriculture: according to the report, the patenting of seeds, plants, or animals hurts developing countries more than it helps them.

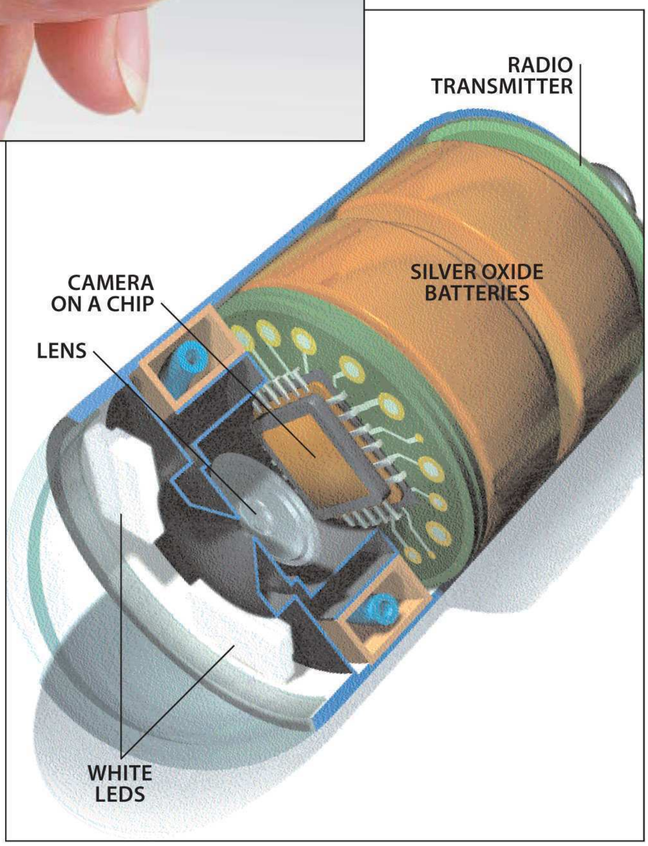
What works for patents can work also for copyright rules. The commission recommends that rather than embracing or ignoring piracy, developing countries ought to accept rich nations' copyright systems. Furthermore, they should adopt the broadest possible fair-use rules and explicitly allow copying documents for educational, research, and library uses. As the report notes, many countries—including South Korea in the 1960s and 1970s and the United States in the 18th and early 19th centuries—used such flexible copyright and intellectual-property protection rules to aid their industrialization.

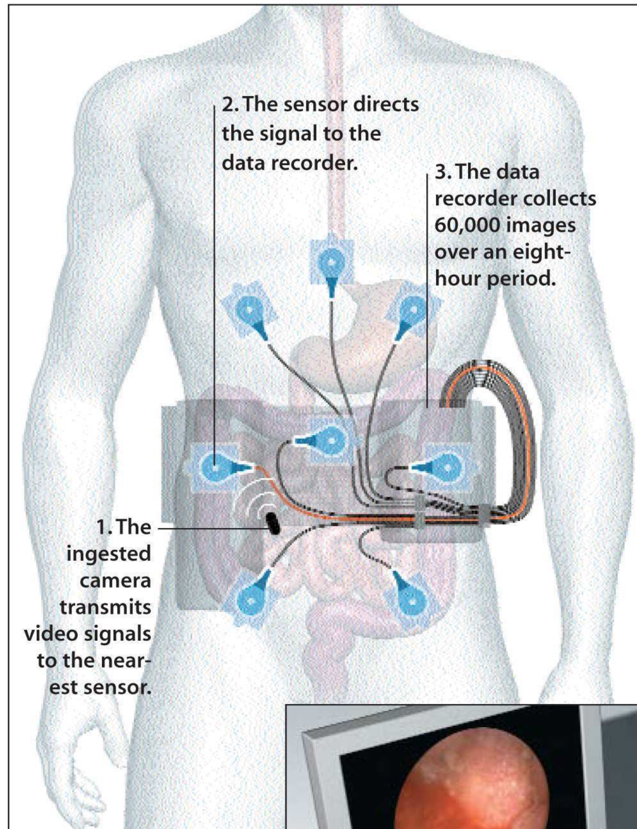
**Rather than ignore rich nations' patent systems, poor nations can adopt such strategies as compulsory licensing. Rich nations can assert intellectual-property rights in a way that will earn respect.**

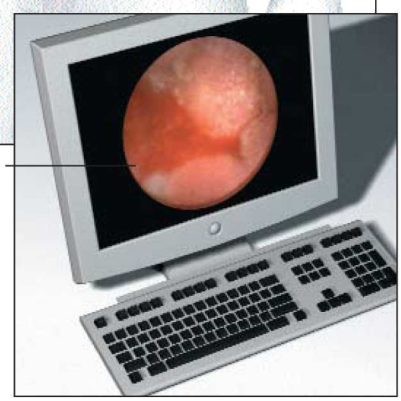
It's important to note that the commission, chaired by John Barton, a patent law professor at Stanford Law School, was not content to show only developing nations how to navigate the icy waters of international intellectual-property policy. The report offers developed nations a strategy for asserting intellectual-property rights in a way that can earn international respect. Developed nations should adopt a nuanced strategy for intellectual-property protection that does not ignore the pressing public-health and development needs of the Third World. In doing so, they will lessen the risk that developing nations will ignore the emerging international intellectual-property system.

What is most refreshing about this report is its implicit view that intellectual-property rights must serve the greater public good. The paramount goals, the commission argues, should be to reduce poverty and help poor nations gain access to needed technologies. Both sides of the intellectual-property debate should heed the report's recommendations. That's a lot to ask: representatives from the U.S. pharmaceutical industry have already bristled at its suggestion of compulsory licensing. But in addition to the stature of the commission members, what gives this U.K. effort traction is the growing recognition that compromise might be the only viable game in town. TR


**Open wide and say "cheese" to the M2A Capsule.**



**4. Images downloaded from the data recorder to a computer workstation reveal previously indiscernible ailments such as bleeding in the small intestines.**

By Tracy Staedter | Illustrations by John MacNeill

## THE INGESTIBLE CAMERA

Seems that there's a pill for everything. But unlike a prescription tablet that treats only the symptoms of a disease, the ingestible camera pill shows what's wrong. Invented by Given Imaging in Yoqneam, Israel, the M2A Capsule takes color images from inside the intestines and transmits them wirelessly for examination. Three key components make it possible: a camera on a chip; a tiny, low-power radio transmitter; and white light-emitting diodes. All are powered by the pill's two silver-oxide batteries. The patient swallows the pill, which for the next eight hours transmits a two-frames-per-second video signal to an array of receivers affixed to its host's midsection. The sensors relay the video frames—some 60,000 in all—to a data recorder worn on the patient's belt. At the end of the examination period, the doctor downloads the video from the recorder to a computer workstation.

Although it can examine the entire gastrointestinal system, the camera pill is particularly valuable for imaging the seven-meter-long small intestine; generally, fiber-optic endoscopes can probe no more than two and a half meters into this organ's narrow, twisting passageway.

Other types of imaging, such as x-ray and ultrasound, are unable to reveal the intestines with enough detail or with color, which is important in the detection of lesions and bleeding. Using the pill, doctors can more easily identify and promptly treat such ailments of the small intestine as Crohn's and celiac diseases. They can also investigate problems such as unexplained abdominal pain and bleeding before those complaints evolve into more serious conditions. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize

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PEOPLE AND ORGANIZATIONS MENTIONED IN THIS ISSUE

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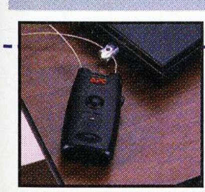

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# THE WHOLE PICTURE

## A limitation of the electron microscope led to the development of holography

Holography is part of our everyday lives—from a commemorative 3-D Elvis on the cover of *TV Guide* to the tiny images designed to discourage credit card counterfeiters. Advances such as holographic video *(see "Holograms in Motion,"* TR *November 2002)* suggest that it will also be a compelling part of our future. All these technologies have their origin in a serendipitous discovery by Dennis Gabor, a Hungarian scientist who was trying to make an improvement to the electron microscope.

The electron microscope, invented in the 1930s, had a resolution power more than a hundred times greater than that of the best light microscopes of the time. However, because the aperture of electron lenses couldn't be increased beyond a certain point, the electron microscope stopped just short of resolving individual atoms. In 1947 Gabor was working at the British Thomson-Houston Company in Rugby, England, speculating on ways to get around this limitation. Gabor thought that perhaps he could take a "bad" picture and then correct it using optical means. Because such a picture would be missing important information—the phase of the electron waves, or their position at a particular point in time—this proved impossible. Gabor theorized that if he could combine the light waves coming off the object with a "coherent reference wave" of the same frequency, the resulting interference pattern would have all the information necessary to construct a 3-D image. Gabor named this interference pattern a "hologram," from the Greek word *holos*, or "whole," because it would contain complete information about the object.

Unfortunately, in 1947 no existing source of coherent light was sufficient to create such images. Gabor and his colleagues continued to research the possibilities of holography for several years, but by 1955 holography had fallen into a period of dormancy.

It was spectacularly resurrected in 1960 with the invention of the laser, which supplied the missing source of coherent light needed to create holograms. In 1962 Emmett N. Leith and Juris Upatnieks of the University of Michigan decided to duplicate Gabor's method using the laser and a technique from their own work developing a type of radar. The next year, they published the first laser holograms: a toy train and a bird. Since then Gabor's principles have been incorporated into devices such as supermarket bar-code scanners and airplane cockpit displays. And if the rash of current activity in 3-D imagery is any guide, holography has a bright future. *—Lisa Scanlon*

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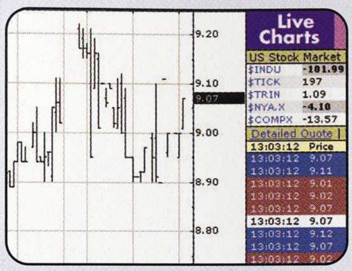


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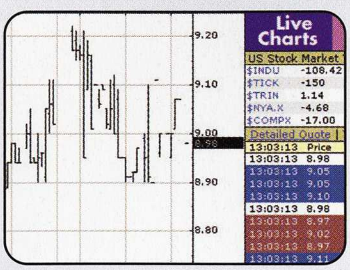


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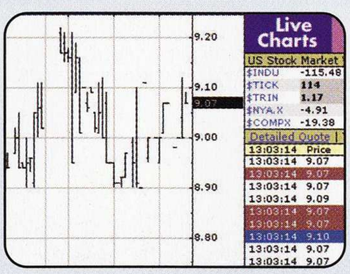


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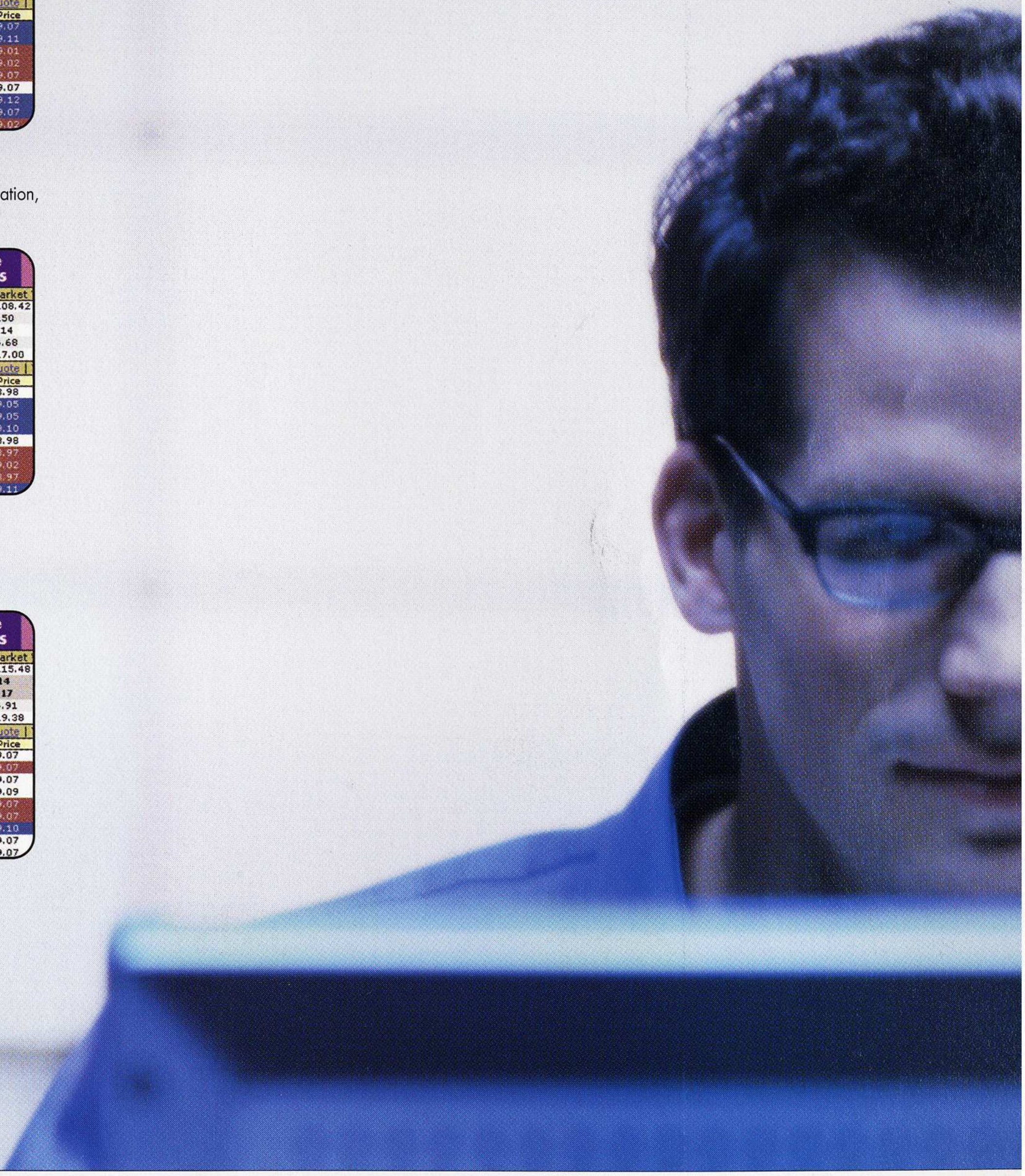

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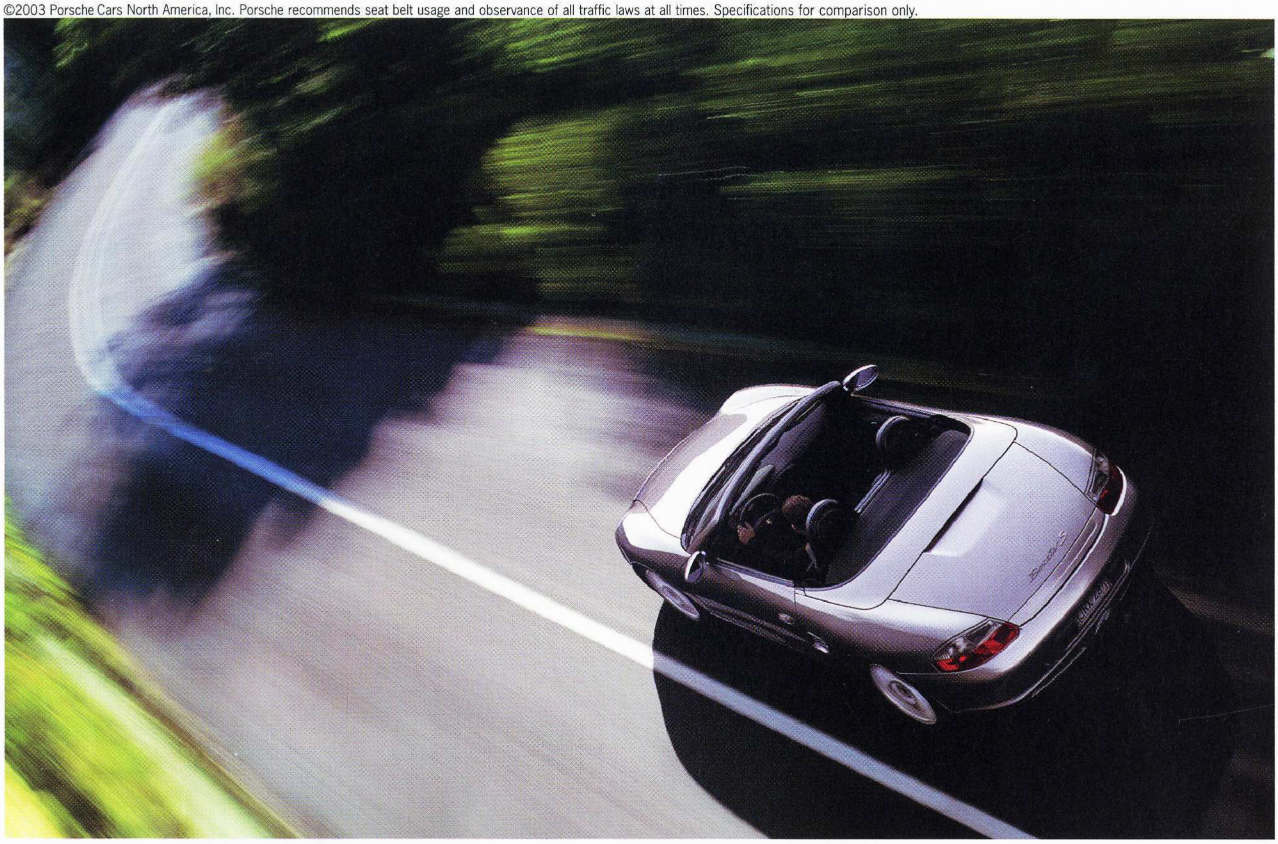

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